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A Stochastic Hybrid Embodied Energy and CO2_eq Intensity Analysis of Building and Construction Processes in Ireland

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Signature Adolf A. Acquaye Date 10th October 2010

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List of Abbreviations

A_{ij}	Input-Output Matrix of Direct Requirement Coefficients
$(I - A)^{-1}$	Leontief Inverse Matrix
i_{dj}	Sub-Sectoral Direct Energy Intensity
i_{Dj}	(Weighted) average sub-sector direct embodied energy intensity
i_{DT}	Sub-sector direct embodied energy intensity of construction sector
€	Euro
BER	Building Energy Rating
BREEAM	BRE Environmental Assessment Method
CASBEE	Comprehensive Assessment System for the Built Environment
CH_4	Methane
CO_2	Carbon dioxide
$CO_{2\text{-}}eq$	Carbon dioxide equivalent
CSO	Central Statistics Office
EC	European Commission
EPA	Environmental Protection Agency
ETS	Emission Trading Scheme
EU	European Union
f(x)	Probability Density Function
$gCO_{2\text{-}}eq$/€	grams of Carbon dioxide equivalent per Euro
GHG	Greenhouse Gases
GJ	gigajoules
GJ/€	Giga Joules per Euro
GWP	Global Warming Potential
$HECO_{2\text{-}}eqI$	Hybrid Embodied CO_2-eq Intensity
IEA	International Energy Agency
I-O	Input-Output
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
j	Sub-Sector
kWh	kilowatt hour

LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LEED	Leadership in Energy and Environmental Design
$MtCO_2$	Million Tonnes of Carbon dioxide
MWh	megawatt hour
N_2O	Nitrous Oxide
NABERS	National Australian Built Environment Rating System
NACE	Nomenclature générale des Activités économiques dans les Communautés Européennes (It translates in English as The Statistical Classification of Economic Activities in the European Community)
OECD	Organisation for Economic Co-operation and Development
RES	Renewable Energy Supply
t	Tonne
ktoe	Kilo Tonnes of Oil Equivalent
x(F)	Quantile Function

Definitions of Key Terms

- **CO_2-eq:**

The equivalent CO_2 (CO_2-eq) is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas

- **Construction Sub-Sector:**

A disaggregation of the construction sector into 'sub-sections' whereby processes and activities of these sub-sectors describes the complete functionality of the construction sector

- **Cumulative Distribution:**

It is a plot of the number of observations falling in or below an interval and it describes the probability distribution of a real-valued random variable (example, embodied CO_2-eq intensity)

- **Deterministic Analysis:**

An analytical evaluation implemented using mean or averages inputs which returns the same results

- **Direct Energy:**

It is the energy input that goes into product manufacture and hence consequently results in the emissions into the atmosphere.

- **Direct Requirement Coefficient Matrix:**

Also known as the Technology Matrix in input-output analysis, it represents the matrix of direct deliveries needed to produce a product per unit of the total output

- **Embodied CO_2-eq:**

The carbon dioxide equivalent released into the atmosphere as a result of the energy embodied in a product

- **Embodied CO_2-eq Intensity:**

The embodied CO_2-eq of a product per unit output; Unit output can be in terms of €, m^2, tonne, etc

- **Embodied Energy:**

The measure of all energy input that goes into producing an end product. It includes energy used in raw material extraction, processing, transportation, storage, all forms of service inputs, etc

- **Emission Factors:**

This is the average emission rate of a given pollutant from a given source relative to the intensity of a specific activity

- **Energy and Emission Policies:**

These are policy instruments designed to reduce the energy use, promote energy efficiency and conversion, renewable energy supplies, etc and the reduction of emissions into the environment

- **Greenhouse Gases (GHG):**

These are gases in the atmosphere that absorb and emit radiations causing the heating of the earth in what is known as the greenhouse effect.

- **Hybrid Embodied Energy Analysis:**

The systematic integration of process and input-output embodied energy analysis to derive the benefits of both methods

- **Indirect Energy:**

It is the energy inputs that occurs upstream of the reference systems

- **Input-Output Analysis:**

It is a top-down linear macroeconomic approach that describes industrial structure as a system of interrelated goods and services and uses sectoral monetary transaction data to account for the complex interdependencies of products and industries

- **Leontief Inverse Matrix:**

This is the matrix of cumulative (direct and indirect) deliveries needed to produce a product per unit of total output and it can be approximated by the power series approximation of the matrix of direct requirement coefficient

- **Life Cycle Assessment:**

The compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

- **Monte Carlo Analysis:**

It is a statistical sampling used in obtaining a probabilistic approximation to the solution of a mathematical equation or model

- **Probability Distribution:**

It describes the range of possible values that a random variable can attain and the probability that the value of the random variable is within any (measurable) subset of that range

- **Process Analysis:**

The measurement in physical terms of all the energy and material flow that goes into the manufacture of a product to produce a unit output and it’s undertaken at an industrial level

- **Stochastic Analysis:**

Stochastic analysis is a statistical approach undertaken by deriving input distributions into a model involving probability of randomness.

- **System Boundary:**

The interface between a product system and the environment or other product system

- **Total Embodied CO_2-eq Intensity:**

The sum of direct and indirect embodied CO_2-eq Intensities

- **Uncertainties:**

It describes the fact that measured values frequently do not match the true values, but differ from them in a probabilistic manner

- **Upstream Emissions:**

Emissions that occur in the negative direction to a product system

Abstract

Given a general lack of research on Irish construction greenhouse gas emissions, a sub-sectoral embodied carbon dioxide equivalent (CO_2-eq) analysis of this sector has been undertaken with the aim of overcoming some methodological challenges such as system boundary constraints, input-output aggregation, double counting of energy inputs and a general lack of data. Using this extended methodology, it is estimated that total embodied CO_2-eq intensity of Irish construction in 2005 was 1,364gCO_2-eq/€ with direct sub-sectoral embodied CO_2-eq intensity averaging 56 gCO_2-eq/€. Some 215gCO_2-eq/€ is estimated to arise from domestic sources including 160gCO_2-eq/€ from domestic indirect emissions. International arising emissions constituted 84% of the total.

The focus of policymakers on regulating energy use in, and emissions from buildings has been on operational energy use ignoring other life cycle components such as embodied energy which can account for a significant portion of life cycle emissions. Data relating to embodied energy and emissions in buildings is limited. However, stochastic techniques can be used to estimate the distribution of emissions intensities in the building sector and sub-sectors. This thesis demonstrates this approach using apartment buildings in Ireland and how it can be used to form the basis for evidence-based policy formulation. A Monte-Carlo simulation suggests that the average probability distribution of embodied CO_2-eq intensity in the sample displays the characteristics of a Wakeby distribution. The average embodied CO_2-eq intensity of the sample of apartment buildings analysed was estimated to be 1,636gCO_2-eq/€ with an uncertainty of 73 gCO_2-eq/€. The distribution also had a long tail which can be targeted for improvement through the implementation of appropriate policies. Two policies are proposed and assessed, one regulatory and one informational. Implementing Policy Option 1 (Regulatory) for example results in an average saving of 450gCO_2-eq/€.

CHAPTER 1: Introduction

1.0 Background

The energy needs of the world have been dependant on fossil fuel and particularly oil. According to Pinderhughes (2004) the consumption of fossil fuel increased by half a billion tonnes a year from the beginning of the 20th century to seven billion tonnes a year by the 1980's. By 1999, 79.5% of the world's total energy consumption was supplied by fossil fuel (World Resource Institute, 2003). This dependency on non-renewable energy resource is unsustainable given its growing demand and the likely reduction in the world's oil reserves and the many challenges (example: technological and economic, etc) facing renewable energy supply (RES) technologies. Bentley (2002) and Abdullah (2005) are both of the view that the world's conventional oil supply has already reached a physical risk and in decline while the OPEC Bulletin (2006) reported that the peak in the world's oil output is not far from us and would occur in the next decade. There is therefore the need to encourage energy conservation as a means of sustaining the world's energy resource. The predictions of increasing energy use, fuels depletion and environmental changes have also led to concerns about security of energy supply but also more detailed calculations and analysis of national and global energy flow systems, energy management and energy use in product manufacture, construction and in industrial processes (Suzuki, 1995 and Rebhan, 2009).

Energy use by various sectors of an economy is mainly classified into industry, transportation, agriculture, commercial and public services and residential sectors. According to a report on key world energy statistics compiled by the International Energy Association (2009) at a global level, the industrial sector consumed 27.5% of total final energy use in 2007. The industrial sector includes a combination of all industrial sub-sectors, such as construction, mining and quarrying and textiles, wood and wood products, etc. The trend is similar in the European countries and developed nations such as the USA, Australia and Japan. In a lighter industrial country (in terms of manufacturing and production) such as Ireland, the industrial sector contributed to 20% of total final energy consumption in 2006 whilst the residential sector contributed 23% (Central Statistics Office, 2009a). The significance of energy consumption by the building and construction sector cannot therefore be over emphasized.

The United Nations Environmental Programme, UNEP (2005) recently reported that building and construction account for more than one third of total energy use and its associated greenhouse gas (GHG) emissions, both in developed and developing countries. At the same time, the sector has largest potential for cutting GHG emissions responsible for global warming. Historically, the construction industry has been Europe’s largest industrial sector contributing approximately 10% of EU GDP (European Commission, 2009a). In Ireland the construction sector is much more important in terms of GNP contribution compared to that of Europe. In 2006 for example, the construction sector in Ireland contributed to 19% of GDP and 23% of GNP; about double the EU average (FINFACTS, 2007). Despite current downturn in the construction industry globally and in Ireland, it can be seen that the building and construction sector is a major contributor to socio-economic development and a major consumer of energy and natural resources in most developed countries including Ireland. The involvement of the building and construction sector in playing a leading role in achieving energy conservation is therefore vital in order to achieve global and national energy efficiency and sustainable development.

Another major reason for the need to conserve energy is the strong link that has been established between fossil fuel consumption and environmental emissions. UNEP (2005) estimates that the 8.6 billion tonnes of building related GHG's emitted in 2004 could almost double by 2030 to reach 15.6 billion tonnes under the Intergovernmental Panel on Climate Change high-growth scenario due to fossil fuel energy use. The US EPA (2009) also recently reported that the construction sector was one of the top emitters of GHG emissions contributing 6% of the total US industrial-related GHG emissions in 2002. It is rated the third highest emitter in the industrial sector only behind oil and gas and the chemical industry. This trend is likely to be no different in other developed countries including Ireland. The report (US EPA, 2009) concluded that even though the aggregate emissions from the construction sector are high, no single construction site or company is a significant contributor. This goes to confirm that energy usage and related GHG emissions of the whole construction industry must be addressed.

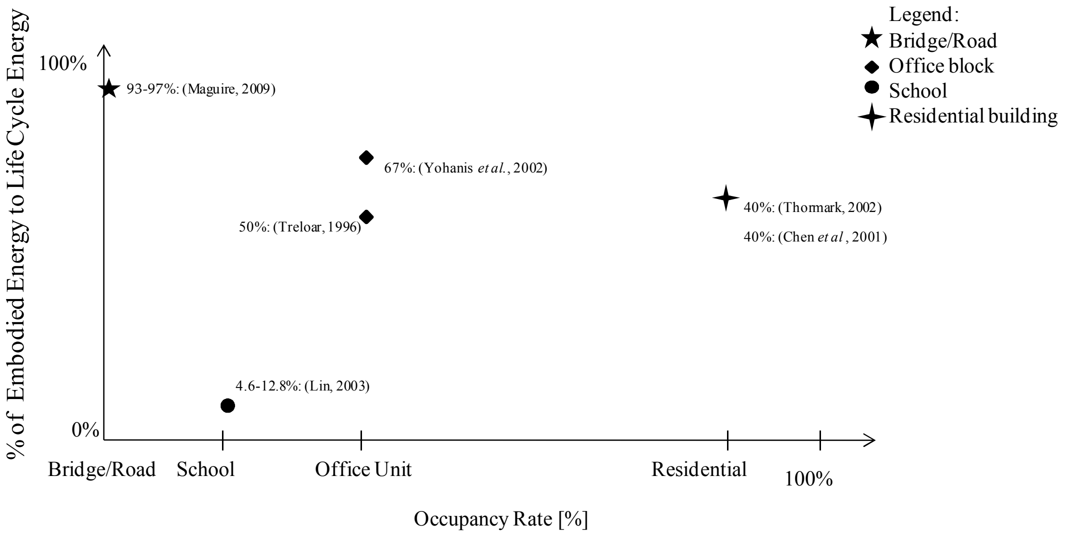
Key global policies such the UN Framework Convention on Climate Change (UNFCCC) produced in Rio in 1992 and the 1997 Kyoto Protocol have been passed to help protect the global environment and promote environmental sustainability. At the European level, energy and environmental policies such as the 2005 European Union Emission Trading Scheme and the 2002 Directive on the Energy Performance of Buildings have also been passed in the past decade to facilitate the uptake of RES technologies and the adoption of energy conservation measures to protect the environment. At the national level, the Irish government published the Energy White Paper in 2007 entitled ''Delivering a Sustainable Energy Future for Ireland''. It describes the actions and targets of the energy policy framework up to 2020. The policies contained therein were driven by three key factors namely; security of supply, cost competitiveness and protection of the environment. A common driver in all global, European Union and national energy and emissions policies is the protection of the environment and a common strategy adopted in all these policies to combat environmental pollution is the conservation and reduction in the use of energy.

One of the key sectors in Ireland where energy policies have been targeted is the building and construction industry. The construction industry is traditionally a major economic sector in Ireland although in the past two years there has been a decline as a result of the global economic recession. But according to the Irish Academy of Engineering (2006) residential and commercial/public buildings consumed 6.16Mtoe in 2002 representing 42.1% of total secondary energy use. The residential sector alone consumed 23% of total energy consumption in 1999 (World Resources Institute, 2003) and 25% in 2006 (Sustainable Energy Authority of Ireland, 2008). These statistics show that in order to fulfil the objectives of the national energy policy, energy use in the building and construction sector must be addressed.

Energy use and associated GHG emissions in buildings can be classified by life cycle stages: embodied, operational and disposal and recycling after end of life use (Cole *et al.*, 1996; and Hubermanand *et al.*, 2008). Whereas operational energy is the energy consumed when the building is been occupied and is in use, embodied energy of a building is the energy consumed by all the processes associated with its production (Reddy *et al.,* 2003). The embodied GHG of a building can therefore be defined as the carbon dioxide equivalent (CO_2-eq) of all GHGs that are emitted into the atmosphere as a result of the energy embodied in the building. The total lifecycle energy use by a building is the sum of its embodied, operational energy, energy required for maintenance and replacement of materials and components and energy used to recycle the building (Yang *et al.*, 2005). According to Masters (2001) embodied energy analysis can be used as an integral part of a full life cycle assessment or it can be used in isolation depending on the particular requirements of the analysis. When used in isolation, it has the advantage that it does not consider natural resources used or the waste produced at each stage of a particular materials or product life cycle.

The energy and CO_{2}-eq emissions embodied in building materials and buildings have been neglected in most energy assessments of buildings because of the difficulty and complexity in assessments although they can be quiet significant (Mumma, 1995). Historically, it is been held that the embodied energy typically comprised about 10% of a buildings total life cycle energy use (Hellingsworth *et al.,* 2002) although contemporary research has shown that this can be higher. Yohanis *et al.* (2002) for example reported that the energy initially embodied in a building could be as much as 67% of the operational energy over a 25 year period. Pullen (2000) also stated that the embodied energy of a building is a very significant portion of the life cycle energy consumption when compared to operational energy use. Other research indicates that the energy embodied in construction is equivalent to 10 - 15 years of operational energy for houses and 4-40 years of operational energy for commercial buildings (ECOSPECIFIER, 2009). Research carried out by the Commonwealth Scientific and Industrial Research Organisation, CSIRO (2006) also showed that as buildings become more energy efficient in their operations, the embodied energy approaches half the lifetime energy consumption. Thormak (2006) also acknowledges this point when he reported that in low energy buildings the embodied energy and consequently the embodied CO_2-eq emission accounts for a considerable part of the total energy use and total CO_2-eq emissions of the building. For unoccupied structures such as bridges and motorways the embodied energy accounts for over 90% of life cycle emissions (Maguire, 2009). Figure 1.1 below shows the variations in the percentage of embodied energy to the total life cycle energy use of different buildings and infrastructure.

Figure 1.1: Variations in the percentage of embodied energy to life cycle energy in different infrastructure projects



The 2007 Energy White Paper for Ireland (Irish Government, 2007) which sets out the energy policy framework from 2007 to 2020 reported the need to reduce total energy consumption by optimising energy efficiency, reducing operational energy use but failed to directly point out the significant energy reductions that can be achieved through considerations to embodied energy in Ireland. This is especially important given that historically, embodied energy research has not been undertaken in Ireland as is the case in other countries in Europe, Australia, United States, Japan and China.

Embodied energy and CO_2-eq analysis and Life Cycle Analysis (LCA) has been used to reduce environmental impact, energy use and costs. These assessments also create common metrics for product comparisons. The development of embodied energy and CO_2-eq analysis and LCA has been progressing over the last three decades under the general guideline of ISO 14000 (Arvanitoyannis, 2008). Due to the oil crises in the 1970s, interest in LCA and its applications was boosted with the development of protocols and standard research methodologies (US EPA, 2006). Traditionally, process analysis has been the method widely used to determine the energy and CO_2-eq embodied in products and it is usually undertaken at an industrial level through the measurements of energy and material flows during production processes. Another methodology, Input-output (I-O) analysis developed by Leontief (1944) to model national economic production flow has since been adopted in energy analysis including embodied energy and CO_2-eq analysis (*inter alia* Bullard *et al.,* 1978; Fay *et al.*, 2000; Treloar *et al.,* 2000; Ozkan *et al.,* 2004 and Blok 2007). Hybrid embodied energy and CO_2-eq energy models which combines the advantages of process and I-O analysis has since been developed (Crawford, 2005).

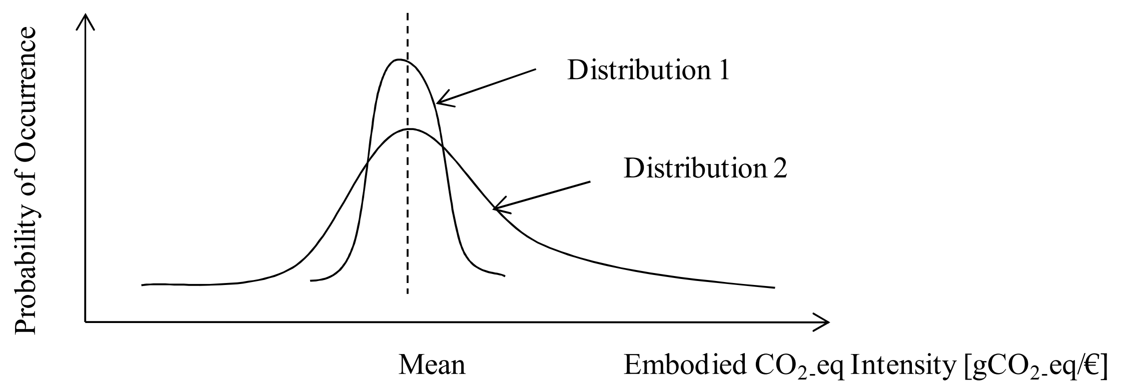
According to Shipworth (2002) and Shih-Chi *et al* (2005), even with substantial methodological improvements made in deriving models for energy assessments in buildings, such models remain deterministic thus obscuring both the uncertainty and true variability in the embodied energy values. For the purpose of policy formulation, an understanding of both the uncertainties and variability in embodied energy and CO_2-eq results is essential. Embodied energy and CO_2-eq intensities of buildings are also used as a indicator as part of a matrix of sustainable assessment tool. Such indicators in a sustainable assessment matrix such as the BRE Environmental Assessment Method (BREEAM) are weighted against each other to determine the overall sustainable performance score for a building. The reliability of the overall sustainability assessment matrix would therefore be reduced when results of embodied energy and CO_2-eq intensities of buildings with unaccounted uncertainties are compared with other sustainability indicators.

The complexity and uncertainty in embodied energy and CO_2-eq analysis is augmented by data issues, variations in technologies and the number, diversity and interactions of processing steps. Data uuncertainties arise in embodied energy and CO_2-eq assessments mainly because of the errors and variability existing in input data as a result of sampling errors, old data, incomplete data, missing data and aggregation. Pacca (2002) also noted that uncertainties can also arise from economic boundary and methodological constraints. Such uncertainties and variability affects decision making. Because results in embodied energy analysis of buildings are used in decision making, such decisions that take into account the uncertainty and variability in results will be much more informed. As Hoel *et al.* (1985) points out a decision made without taking uncertainty into account is not worth making at all. The need for estimating both the uncertainties and variability in embodied energy data and results is best addressed through the development of a stochastic modelling framework (Shipworth, 2002).

Deterministic embodied energy values have been calculated for a variety of building types in different countries. Treloar *et al.* (2001) calculated the embodied energy intensity of a residential building in Australia to be 0.851GJ/\$100. Reddy *et al.* (2003) also estimated the embodied energy intensity of a reinforced concrete framed structure in India to be 4.21GJ/m^2 while Thormak (2002) calculations suggested that the embodied energy of a Swedish apartment was 2.9 GJ/m^2. Due to the constraints mentioned above, these data may be representative of a very small sample of buildings in the overall sector. This does not provide sufficient information for decision makers to identify methods of reducing energy consumption in the construction supply chain. If however, the distributions of embodied CO_{2}-eq can be estimated using stochastic analysis, then decision makers can design policies, supply chains and buildings to reduce the overall emissions in an industry sector or market segment.

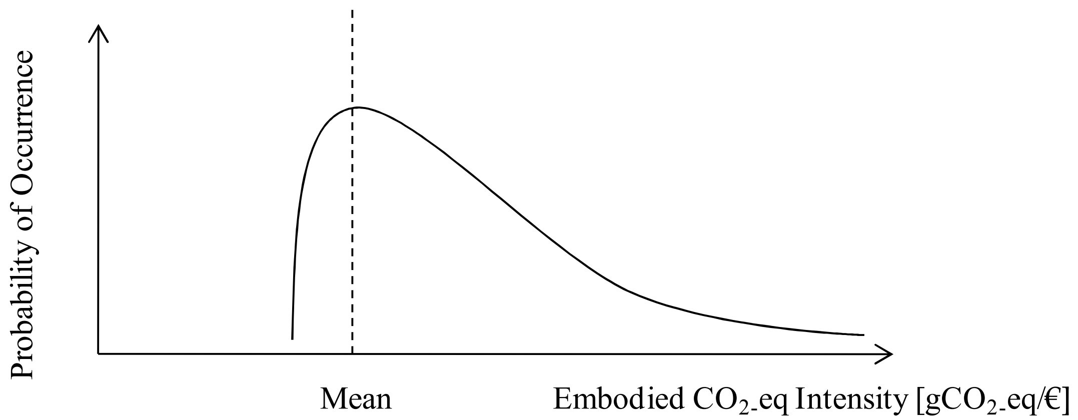
An understanding of the distribution of embodied emissions in the construction sector or segment is useful in providing detailed information which can form the basis for the formulation of effective policies. For example, two possible embodied CO_{2}-eq intensities probability distributions are shown in Figure 1.2 below.

Figure 1.2: Two possible Normal Embodied CO_{2}-eq Probability Distributions



Both have the same mean but different standard deviations: probability distribution 2 is more dispersed than distribution 1. From a policymaker's perspective, there is more scope to regulate to reduce the mean emissions intensity in the case of 2 than of 1 since designs, processes and products with energy intensities below the mean are more widely deployed. Figure 1.2 shows normal distributions of embodied emissions. However, a skewed distribution such as that illustrated in Figure 1.3 below shows that under current industry practices, there is a minimum achievable emissions intensity beyond which discontinuous technological learning is required to effect reductions; policymakers must be cognisant of this barrier. On the other hand, the long tail of high emissions for a minority of buildings might be targeted for improvement.

Figure 1.3: A Skewed Embodied CO_{2}-eq Probability Distributions



1.1 Research Motivation

i. General lack of research especially on embodied energy and CO_2-eq analysis in Irish construction

Despite the likely importance of construction activity to Irish environmental emissions, there is a general lack of research on Irish construction (Forum for the Construction Industry, 2003 and UCD Energy Research Group, 2007) especially on embodied energy and embodied emissions. In countries such as Australia and the USA, research on construction sector embodied emissions has led to many initiatives to reduce the construction sector total energy consumption and embodied emissions.

ii. Assessment techniques will be needed and used to drive any policy measure that may be implemented by countries such as the Irish Government if EU and

National Energy Directives are to extend to the energy and CO_2-eq embodied in buildings.

Building environmental assessments tools such as BREEAM – UK; LEED – US; TGBRS – India; CASBEE – Japan; NABERS, Australia, etc have been developed over the years to measure the environmental performance of buildings and it's usually based on a number of performance-based indicators. These tools are mainly used voluntarily and as a basis for specifying a minimum environmental performance level for their new buildings. Building environmental assessment tools are usually not consistently LCA based and include broader range of considerations such as social and economic performances (Haapio *et al,* 2008). In current environmental research, Life cycle assessment has been generally accepted as the basis for comparisons of resources and materials, components and even whole products including buildings. LCA assessment tools include EcoQuantum-Netherlands; SimaPro-Netherlands; EcoEffect-Sweden; ENVEST-UK and ATHENA-Canada. The difficulty and complexity of gathering LCA data for products has led to prioritization of data gathering often leading to the neglect of embodied energy considerations which has traditionally been assumed to be negligible relative to the total life cycle energy. It is therefore imperative that embodied energy and CO_2-eq tools should be developed for use to assess the energy and CO_2-eq embodied in buildings. Results from such a tool can be used to inform policy making on energy embodied in products.

iii. With growing global concerns over energy use, material and resource consumption and the emissions of CO_2 into the atmosphere, the energy embodied in buildings and construction processes have become important and a key issue that needs to be tackled in the design stages of construction in order to strive towards sustainable construction.

Given that the energy embodied in building is a significant portion of the total life cycle energy consumption of a building (*inter alia* Mumma, 1995; Pullen, 2000; Hellingsworth *et al.,* 2002 and Yohanis *et al.,* 2002) global efforts to reduce energy consumption in the building and construction sector cannot be totally achieved by ignoring the energy embodied in buildings. This suggests an approach that would account for all energy consumption from cradle-to-grave. In constructing a building with a low embodied energy component, decisions about material selection, construction process and design options, etc must be taken at an early stage of design where design changes can be made and preferential low embodied energy materials selections adopted. Environmental assessments such as considerations to embodied energy undertaken at the early design stage are more likely to aid in the selection of sustainable materials and to minimise the use of energy (NBS, 2008).

iv. Embodied energy and CO_{2}-eq emission methods are very dependent on the source, availability and geographical use of data. As such, the methodological development will make use of best available data from Ireland in order to achieve results which is representative of the current state of energy use and emissions in the Irish building and construction sector

Embodied energy and CO_{2}-eq inventories which have geographic consistency are able to provide more accurate results or impacts assessments. For example, emissions factors derived for Ireland using primarily data from Ireland such as electricity mix and energy tariff would provide better emissions estimates than using approximated emission factors derived from other countries. In defining the scope of an embodied energy study, the geographic boundaries of the study should be clearly defined and input data should represent the characteristics of the system within the geographical boundaries. This is because embodied energy and CO_2-eq studies undertaken using mainly regional or global data may not be applicable locally. It is an established fact that differences in data caused by unrepresentative data for example is an important source of uncertainty in embodied energy assessments. Non-representative data is the cause of geographical and technological differences from country-to-country. Weidema (1998) reported that geographical and technological differences corresponds to the degree of accordance between the production conditions and all other aspects of correlation in the area relevant for the study and in the geographical area covered by the data obtained. In order words geographical and technological differences refers to the differences between the conditions and all other aspects of data differences in the area relevant for the study (or system boundary) and in the geographical area covered by the data obtained. Embodied energy and CO_2-eq tools which have been developed suffer from this problem of geographic and technological differences. There are developed as generic tools and not specific to countries such as Ireland. This study would therefore aim to use as much data as possible specific to Ireland in order to generate relevant impact assessments.

v. The derivation of a stochastic probability distribution of embodied energy and embodied CO_2-eq of residential buildings in Ireland can be used in benchmarking the energy and CO_2-eq intensities of buildings in the industry

Shipworth (2002) stated that recent efforts to methodologically improve assessments of energy and CO_2-eq embodied in buildings have been limited to deterministic models.

This therefore obscures both the uncertainty and true variability in the embodied and CO_{2}-eq energy values. A stochastic approach however ensures that variability in input data can be captured and the results presented as probability and cumulative distributions with known statistical parameters. These distributions can form the basis for the benchmarking of the energy and CO_{2}-eq intensities of buildings as well as provide a basis for evidence based policy formulation.

vi. In the formulation of energy and emissions policy measures on embodied energy and CO_{2}-eq intensities of buildings, an indication of the variation in intensities across the buildings sector can ensure that initiatives are taken to shift the energy intensities of buildings down the lower end of the distribution.

Sustainable building has three principles relating to energy and environmental issues. These are reduction in energy use (operational energy), reduction in embodied energy and resource depletion and to minimise external pollution, waste and environmental damage (US Green Building Council, 2009). In Ireland for example, there is regulation in place to tackle operational energy use in buildings in the form of the Building Energy Rating scheme. A number of regulations exist regarding pollution, waste and environmental damage. There is however no direct regulation for embodied energy even though it is a key principle in sustainable building designs. This is no different in other countries. According to Oppoenheim *et al.* (1996) no country has yet developed specific embodied energy regulations. It is also not a mandatory requirement to include embodied energy when calculating national minimum energy requirements in the recast of European Energy Performance of Building Directive (Lanskaya, 2009). The reasons for this might be the complexity in assessments, the traditional notion that energy embodied in buildings are not significant compared to the total life cycle energy usage and possible lack of information and policy initiatives on embodied energy and CO_2-eq research. One such initiative which can help in policy formulation is an indication of the variation of embodied energy and CO_2-eq across the building sector. This can be achieved through the stochastic analysis of embodied energy and CO_2-eq across the building sector.

1.2 Research Aims and Objectives

The research aims to develop a stochastic policy assessment methodology and demonstrate its use taking into consideration data availability and limitations in Ireland and to explore usefulness of uncertainty in evidence based policy making. Specific objectives include:

i. Review existing embodied energy and CO_2-eq methodologies and data requirements, identify improvements in input-output aggregation and system boundary completeness and calculate the embodied energy and CO_2-eq intensity of Irish construction at a disaggregated level of analysis.

ii. Develop a stochastic embodied energy and CO_2-eq assessment modelling framework incorporating process and input-output analysis and treatment of uncertainties. This is applied to apartment buildings in Ireland in order to gain an understanding of its embodied CO_2-eq intensity distributions.

iii. Investigate how new and relevant data can be incorporated into embodied energy and CO_2-eq emission distributions using Bayesian Updating technique.

iv. Examine the role that stochastic embodied CO_2-eq assessment can play in evidence based policies and test identified policies across the apartment building sector.

1.3 General Research Methodology

An embodied energy and CO_{2}-eq intensities framework is developed using a hybrid analysis which draws on the advantages of process analysis and input-output analysis using primarily data from Ireland. Some novel approaches that are investigated and adopted in the framework consist of the disaggregation techniques relating to the Irish construction sector and input-output data. The expansion of the input-output system boundary is also investigated. The hybrid model integrates process energy and CO_{2}-eq intensities of building materials, direct energy and CO_{2}-eq intensities derived for the construction sub-sectors and from economic data for Irish construction firms and input-output indirect energy and CO_{2}-eq intensities derived from the national input-output tables.

To achieve a stochastic embodied energy and CO_{2}-eq intensities model, Monte Carlo technique is adopted and used to derive probability distributions while capturing uncertainties and variability for input parameters into the novel model. Seven apartment buildings in Ireland are used as case studies in implementing the stochastic model. A probability embodied energy and CO_{2}-eq distribution for apartment buildings in Ireland is derived. The probability distribution shows the variations in energy and CO_{2}-eq intensities and probabilities of occurrence that exist across apartment buildings. Statistical analysis and case study scenario analysis are undertaken on the probability embodied energy and CO_{2}-eq distributions.

Bayesian updating technique is presented and shown how it can be used to update the derived prior embodied energy and CO_{2}-eq distributions with new data to the posterior distribution and the resulting uncertainty in the distribution analysed.

Relevant policies were then identified based on the stochastic framework and assessed on their effectiveness in reducing embodied CO_2-eq in buildings using the probabilistic embodied CO_2-eq intensity distributions.

Detailed methodologies adopted in the thesis are presented in Chapter 3.

1.4 Main Assumptions

The main assumptions made in the research include the following:

i. In calculating direct embodied energy and CO_2-eq intensities, disaggregated construction sector data obtained from the Central Statistics Office Census of Building and Construction was used instead of aggregated input-output data. It is assumed that the use of disaggregated construction sector data represents a better estimation of energy consumed on site by construction companies than sectoral data compiled from the national accounts and wide variety of other sources. This is because the disaggregated data is specifically collected by construction firms on their direct energy consumption.

ii. The use of input-output analysis is based on a number of assumptions such as proportionality assumption, homogeneity assumption and the conversion of economic data into physical quantities such as energy and CO_2-eq intensities, etc. These assumptions are expanded upon in Chapter 2 and some of these are dealt with in Chapter 4.

iii. In the stochastic model development, sectoral indirect input-output embodied CO_2-eq intensities was assumed to be deterministic or of constant (average) value. This is because, national input-output data are compiled from large varieties of sources including government, private and industrial and commercial publications. These data are usually aggregated with wide variations and uncertainties across all 53 aggregated Irish sectors. There was therefore no particular basis to estimate the distribution that fits the general input-output data. Nawrocki (2001) for instance asserts that assuming distributions for input data can result in more errors during modelling. It is however recognized that uncertainties in the input-output data may change the results. Lenzen *et al.* (2000) estimated the errors in I-O data depends largely on the error in the respective source data but is in the region of 20%.

iv. The average embodied CO_2-eq intensity distribution for apartment buildings in Ireland is derived from limited number of case studies because of lack of data. The distribution can however be updated whenever new data becomes available.

1.5 Contributions to Knowledge

The contributions of this study to knowledge in the area of embodied energy and CO_2-eq research are outlined below:

i. National

There is a general lack of research on the construction sector in Ireland especially on embodied energy and CO_2-eq analysis. This study has initiated research in this area in Ireland. The study also generally demonstrates how limited national data is used to conduct embodied energy and CO_2-eq intensity assessments.

A Multi Regional Input-Output (MRIO) model consisting of Irish domestic and Irish import direct requirement coefficient matrix and Leontief inverse matrix was developed for Ireland. This model ensures the system boundary completeness when undertaking lifecycle, embodied energy and CO_2-eq assessments.

ii. Methodological Advancements

The thesis shows how the construction sector is disaggregated into five sub-sectors and derived direct sub-sectoral intensities of construction processes integrated into a hybrid embodied energy and CO_2-eq assessment. Furthermore, 'Disaggregation Constants' are derived and used to disaggregate the Irish input-output energy supply sectors and it is also shown how its use helps to avoid double counting of energy supply in input-output analysis.

iii. Formulation and Application of Stochastic Embodied CO_2-eq Model

In this thesis a stochastic hybrid (process and input-output) embodied CO_2-eq intensity relationship was developed. The study also demonstrated the application of this relationship and how it can be used to estimate uncertainties in embodied CO_2-eq assessment

iv. Identification and Testing of Embodied CO_2-eq Abatement Policies

Two embodied emissions policies were developed and it was shown how stochastic embodied CO_2-eq framework was used as a policy development tool to test the effectiveness of these policies.

1.6 Thesis by Chapters

This sub-section provides readers with an outline of the thesis by briefly summarizing the main sub-sections covered in each chapter.

Chapter 1 Introduction

- Background
- Research objectives
- Research motivation
- General research methodology
- Main assumptions
- Contribution to knowledge

Chapter 2 Literature Review:

- Embodied energy and CO_{2}-eq analysis framework
- Process embodied energy and CO_{2}-eq methodology
- Input-output embodied energy and CO_{2}-eq methodology
- Hybrid embodied energy and CO_{2}-eq methodologies
- Deterministic and stochastic embodied energy and CO_{2}-eq modelling
- Types, quantifying and processing uncertainty in embodied energy and CO_{2}-eq intensities
- Building sector energy and emission policies

Chapter 3: Research Methodology

- Methodology used in calculating total energy and CO_{2}-eq intensity of Irish construction and Irish construction sub-sectors at disaggregated Level
- Methodology for the stochastic hybrid embodied CO_{2}-eq intensity (HECO_{2}-eqI) of Apartment Buildings in Ireland
- Methodology used in assessing proposed building and construction sector emissions policies

Chapter 4 Construction Sector and Sub-Sectors Embodied Energy and CO_2-eq Intensity Analysis

- Construction sub-sector embodied energy and CO_{2}-eq analysis
- Derivation of sub-sectoral direct energy intensities
- Re-derivation of Input-Output direct requirement and Leontief inverse matrices for system boundary extension
- Disaggregation of Energy Supply Sectors
- Calculations of indirect input-output embodied energy and CO_{2}-eq intensities
- Analysis of construction sector national and international arising embodied energy and CO_{2}-eq intensities and tier level decomposition of embodied energy and CO_{2}-eq intensities

Chapter 5 Stochastic Hybrid Embodied Energy and CO_{2}-eq model development

- Monte Carlo analyses and Derivation of stochastic input variables
- Stochastic Model: Hybrid embodied CO_{2}-eq intensities

- Application of Hybrid Embodied CO_{2}-eq Analysis: Case Studies
- Derivation of probabilistic embodied CO_{2}-eq distributions for apartment buildings in Ireland
- Statistical analysis of embodied CO_{2}-eq intensities
- Application of Bayesian Updating technique to embodied CO_{2}-eq uncertainty analysis

Chapter 6 Embodied Energy and Emissions Policies

- Policy perspective analysis of construction sub-sector and input-output embodied energy and CO_{2}-eq intensities
- Policies design targeted at limiting embodied emissions derived from stochastic embodied CO_{2}-eq intensity distributions
- Assessment of policy options effectiveness in reducing embodied emissions

Chapter 7 Conclusion of Thesis and Recommendations for Future Research

CHAPTER 2: Literature Review

2.0 Overview

The chapter begins with a review of literature by defining embodied energy and embodied CO_2-eq of a building and presenting the two main methodologies employed in embodied energy and embodied CO_2-eq analysis. Next, the chapter presents the scientific thinking on the subject by presenting the frameworks and steps for embodied energy and embodied CO_2-eq analysis.

Embodied energy and embodied CO_2-eq methodologies are discussed emphasising their respective strengths and weaknesses. The general methodological approaches are then presented highlighting the area where methodological improvements can be made.

A review is undertaken of the two main modelling techniques of embodied energy and CO_2-eq analysis, discussing their respective applications in literature, their strengths and weaknesses and how new applications in embodied CO_2-eq analysis can be undertaken using the modelling technique.

Embodied CO_2-eq uncertainty analysis is then discussed and the type and quantification of uncertainties reviewed. It is then shown how embodied CO_2-eq analysis modelling technique can be used to quantify uncertainties across the building sector.

The chapter concludes by presenting energy and emissions policies in the building sector, building sector energy and emissions policy classifications and a discussion on the limited policies directly targeted emissions. Finally, it is shown how embodied CO_2-eq analysis modelling techniques can form the basis for the formulation of evidence-based emission policies in the building sector.

2.1 Embodied Energy and CO_{2}-eq Analysis

Scheckel (2005) defines embodied energy as the measure of all energy input that go into producing an end product. The CO_{2}-eq embodied in a building can therefore be defined as the equivalent CO_2 emitted as a result of the energy embodied in a building.

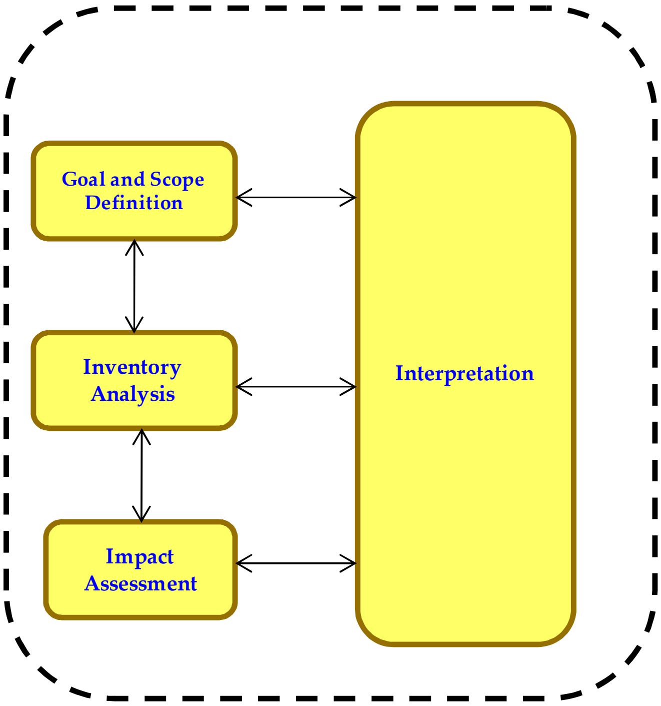
Fundamentally, there are two base methods for determining the energy embodied and CO_{2}-eq emissions associated with the production of a product such as a building. These are the industrial-based process analysis and the economically-based input-output analysis (Masters, 2001 and Munksgaard, 2000). These two base methods can be combined into a third method; the hybrid methodology. Embodied energy and CO_{2}-eq analysis is an important part of life cycle energy analysis. Whereas embodied energy is particularly concerned with the energy content that goes into the production of a product, life cycle energy analysis evaluates the energy associated with a product throughout the whole lifecycle of the product but both are based on the same framework.

2.1.1 Embodied Energy and CO_{2}-eq Analysis Framework

The framework for embodied energy and CO_{2}-eq analysis is based on ISO 14000 series of environmental management standards which were developed by the International Standard Organisation and numerous organisations such as United National Environment Programme (Sonnemann *et al.,* 2004) and the Society for Environmental Toxicology and Chemistry (Horne *et al.,* 2009) as a systematic process for identifying, quantifying and assessing the environmental impacts throughout the lifecycle of the product, process or activity. ISO 14040 and ISO 14044 specifically provide the principles, framework, requirements and guidelines for conducting embodied energy and CO_{2}-eq assessments (International Standard Organisation, 2006). The concept of embodied energy and CO_{2}-eq analysis thinking considers energy use and emissions released to the environment in the manufacture of a product.

The ISO 14040 standards describes the principles and framework for life cycle assessments (LCA) and are designed to provide guideline on applications and limitations and definition of terms but does not specify methodologies for different LCA phases. It is rather general given that the guideline was designed for a wide variety of industries. It does however provide approaches for review and an appendix describing the application of LCA. ISO 14044 standards specify requirements and provide guidelines for LCA. The standard is also designed to provide guidelines for the preparation, conduct and critical review of inventory analysis, impact assessment and interpretation of results.

Figure 2.1: Embodied Energy and CO_{2}-eq Analysis Framework (ISO, 2006)



According to the ISO 14040 and 14044 standards (International Standard Organisation, 2006), a traditional lifecycle assessment framework consists of the following four phases: goal and scope definition; inventory analysis; impact assessment; and interpretation of results. Embodied energy and CO_{2}-eq analyses can be used as a form of streamlined form of LCA (LCA usually addresses a broader range of environmental parameters) where the environmental parameter and lifecycle stage is limited.

Table 2.1: Steps in Embodied Energy and CO_{2}-eq Analysis

Step in Analysis	Purpose/Results	Significance/Results/Benefits	Comments
Goal Scope and Definition	Defines purpose of study. Sets boundaries. Establishes functional unit.	Depends on subject and intended use of the study. Sets stage for entire analysis. Breadth and depth of the study can vary considerably depending on the goal.	Must be clearly specified.
Inventory Analysis	Provides inventory of input/output data of the system under study.	Data are collected to meet the goals of the study.	Data collection is resource intensive. Data may not be available at level needed. Data may be confidential.
Impact Assessment	Provides information to understand and assess the magnitude and significance of the potential environmental impacts associated with the inventory results.	Provides a system-wide perspective of environmental and resource issues.	Standard impact categories may not be sufficient to identify and assess all impacts. LCIA results indicate potential environmental effects; they do not predict actual impacts.
Interpretation of Results	Provides conclusions and recommendations based on the results of the inventory and impact assessments.	Uses a systematic approach to identify, evaluate, and present conclusions to meet the requirements described in the goal and scope.	

Adopted from (ISO, 2006)

2.2 Phases of Embodied Energy and CO_2-eq Analysis

2.2.1 Goal and Scope Definition

The goal and scope definition in an embodied energy and CO_2-eq analysis defines the purpose and methodology including environmental impacts into the decision-making process. In this phase, the following items must be determined: relevant information needed to add value to the decision-making process, how accurate the results must be to add value, and presentation and interpretation of results in order to be meaningful and usable. For example, the goal of an embodied energy and CO_2-eq analysis of a building would consist of the intended application of the study which can be for purpose of information, the reasons for conducting the study and the intended audience of the analysis.

The scope identifies the product system to be studied and the functional unit of the system. The functional unit of a building system will provide a quantitative reference such as the gigajoules (GJ) of energy the building consumes or CO_2-eq emissions to the environment to the cost of the building in monetary terms (e.g. Euros). An important scope definition is the system boundary of the study, data requirements and any assumptions and limitations.

2.2.2 Inventory Analysis

Embodied energy and CO_2-eq analysis inventory analysis involves the collection and organisation of all relevant data. This is an important stage because the level of accuracy and detail of the data collected is reflected throughout the analysis. Some of the data collected for the embodied energy and CO_2-eq analysis of a building will include energy intensities of building materials, emission factors, bill of quantities, and national environmental statistics data.

Results of the inventory analysis details the quantities of emissions released into the atmosphere or the energy consumed. It is useful in comparative analysis and may form the basis for identifying policy options and legislations as shown in Chapter 6 in this study.

2.2.3 Impact Assessment

The impact assessment phase of embodied energy and CO_2-eq analysis involves the evaluation of the environmental emissions identified in the inventory analysis on human health and on the environment. For a building, the impact assessment can aggregate CO_2, methane and other greenhouse gas emissions (GHG) into a single impact assessment category such as climate change or global warming as an equivalent of weighting in terms of CO_2-eq. While this measure is not an impact per se, it provides a numerical measure of the potential impacts of climate change on global warming. In the embodied energy and CO_2-eq analysis in this study, the environmental impact category of interest is global warming; hence environmental emissions caused as a result of energy use are classified according to their global warming potential. This is achieved by characterizing the impacts of the emissions (CO_2, methane, nitrous oxide) using the global warming potentials (IPCC, 2006).

2.2.4 Interpretation of Results

Interpretation of embodied energy and CO_2-eq analysis results involves a systematic identification, quantification and evaluation of results from the inventory and impact assessments which are then communicated effectively to the target audience. According to ISO (2006), the interpretation of embodied energy and CO_2-eq analysis results must meet the following objectives:

- Analyse results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the analysis and report the results of the analysis in a transparent manner.
- Provide a readily understandable, complete, and consistent presentation of the results of an embodied energy and CO_2-eq study in accordance with the goal and scope of the study.

2.3 Embodied Energy and CO_2-eq Analysis Methodologies

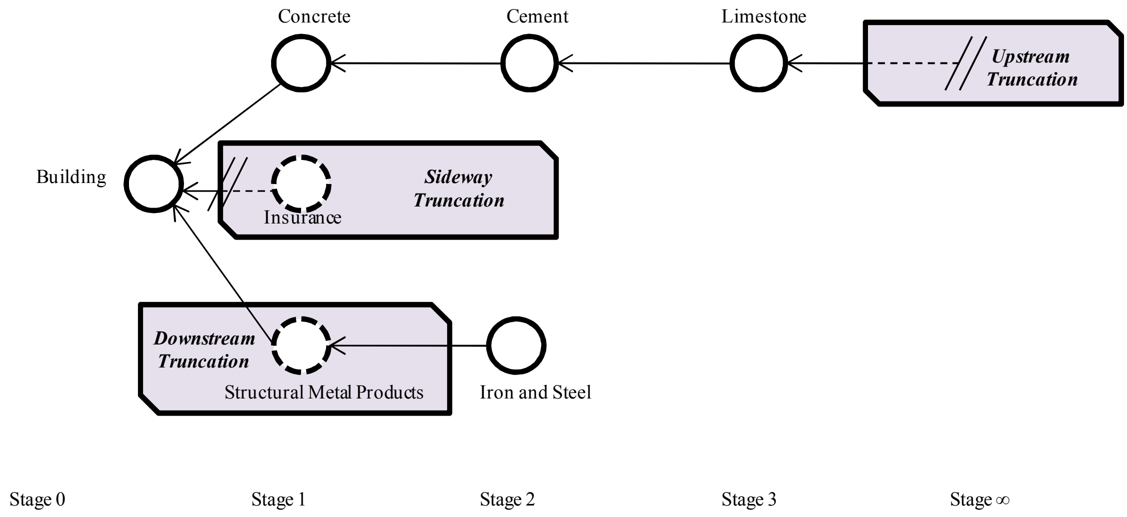
There are two base approaches to embodied energy analysis; these are process analysis and input-output analysis. Process-based embodied energy and CO_2-eq analysis utilises process flows to systematically gather data and compute known environmental inputs and outputs. Input-output analysis which was developed as an economic analysis technique by Leontief (1936) uses economic transaction between various sectors of the economy to determine energy intensities as an output of monetary value. Recent research studies on embodied energy methodologies have focussed on hybrid models that combine the advantages of the process and input-output analysis (see *inter alia* Bullard *et al.*, 1978, Treloar, 1997; Lenzen *et al.*, 2000 and Stromman *et al.*, 2008).

2.3.1 Process Analysis

Process analysis is undertaken at an industrial level by measuring the input and output of energy and materials during the manufacturing processes of a product. The sum of all the energy used directly and indirectly during the manufacture of the product per unit output of the product is the process energy intensity normally expressed as GJ/unit weight, GJ/unit area or GJ/unit length for that particular product. The embodied energy of a product is evaluated by multiplying the energy intensity by the quantity of materials used in tonnes and an appropriate waste factor. In the case of construction, the waste factor is the ratio of a delivered quantity of material to the quantity of material used on site. Its use enables the actual delivered quantity of materials to the construction site to be used in the analysis.

Process analysis is time consuming to undertake because all the energy inputs that go into the production of a product are numerous (theoretically infinite) and therefore impossible to determine. Furthermore, it is likely to ignore some processes such as services which include banking, insurance and finance as well as auxiliary activities like administration and storage. As a result a system boundary is set so that a finite number of important energy inputs can be considered. According to Born *et al.* (1996) the setting of the system boundary results in truncation of the analysis resulting in errors in the embodied energy values. Lenzen *et al.* (2002) estimated that the magnitude of the incompleteness varies with the type of product or process and depth of the study, but can be 50% or more. However, where all the important energy inputs in each stage of the industrial processes within the system boundary are known and can be analysed separately it is regarded as a more accurate method than input-output analysis (Mattila *et al.,* 2010).

Figure 2.2: Upstream, Downstream and Sideways Truncation Errors in the Buildings System Boundary



Adapted from Crawford (2009)

When a system boundary is being defined, it is important to include every step of the process that can affect the overall results and interpretation of the analysis. In special instances where the embodied energies of alternative products are being compared, identical processes in both products can be excluded from the system boundary. In such instances, the framework for the comparison must be recognized as relative because the total system boundary excludes certain energy contributions. Because of the complexity of energy inputs into the production of building, different types of truncation occurs as illustrated in Figure 2.2. One of the major flaws of a process analysis and the reason for the system boundary truncation is because it is impossible to know the full potential of higher order processes if these have not been quantified. Thus the need for I-O analysis.

Baird *et al.,* (1997) state that the level of analysis conducted in a process analysis has a major effect on the system boundary. For example, if the level of analysis is limited to the first stage which includes the direct measurements of energy inputs into the product system, the system boundary is limited to less than 50% of the total life cycle. Crawford (2008) also showed that truncation associated with process analysis can be up to 87%, with capital equipment also accounting for up to 22% of the total inputs to a particular product. A breakdown of the levels of analysis undertaken in process methodology and the system boundary covered is presented in Table 2.2 below.

Table 2.2: Levels of process analysis and level of system boundary covered

Level of Analysis	System Boundary Covered	Energy Inputs
Level 1	Typically less than 50%	direct energy of the process.
Level 2	Frequently around 40%	energy used in material extraction
Level 3	Rarely greater than 10%	energy used to make capital equipments.
Level 4	Usually very low	energy used to manufacture the machines used in making the capital equipments.

Adapted from Baird *et al.,* (1997)

According to Lenzen *et al.* (2000), the system boundary of process analysis is usually chosen with the intention that the addition of a successive level has a negligibly small affect on the total embodied energy of the product.

2.3.2 Input-Output Analysis

Input-output energy analysis follows the flow of materials in an economy in order to determine the amount of primary energy required to produce a certain product or service. Whereas in process analysis, the flows are expressed in physical quantities, in input-output analysis, the flows are expressed in monetary terms. The flows of materials in an economy is organised into an input-output table. According to Lenzen *et al.* (2003) I-O analysis provides a top-down linear macroeconomic approach to describe industrial structure in which sectoral monetary transaction data are employed in an inter-industry model to account for the complex interdependencies of industries in modern economies. Treloar (1998) also states that I-O analysis is a comprehensive embodied energy analysis framework which uses a systems approach to model the flows of products between sectors of an economy such that the detailed processes are represented by the average activity of each sector. The concept of input-output analysis has been applied to ecological and industrial systems (Bailey *et al.,* 2008), environmental emissions (Hayami *et al.,* 1997), waste management (Nakamura, 2006), energy and embodied energy analysis (Park *et al.,* 2007) and energy systems (Crawford *et al.*, 2004 and Crawford, 2009). I-O embodied energy and CO_{2}-eq analysis is best suited to calculate indirect effects of energy and CO_{2}-eq emissions in a systematic and complete accounting framework. The use of input-output data assists in improving the system boundary completeness of lifecycle inventories (Crawford, 2008). The main data used in I-O analysis in this study are the Irish input-output table.

An input-output table is a summary of all deliveries between producer, trader and consumer. It is an economic map which shows how the economy is broken down into various sectors and the inter-relationships between all the economic sectors.

Assuming an input-output table is organised into n sectors, the main input-output table is a $n \; x \; n$ matrix where by each cell of the matrix describes the deliveries between two particular sectors. The rows and columns of the matrix describe the supplying and receiving sectors respectively.

By way of example, take for example an economy with three sectors: fabricated metal products, machinery and equipments and electricity and gas as shown in Table 2.3 with the only consumer being the construction sector.

Table 2.3: A 3-Sector Input-Output Table

		1 Fabricated Metal	2 Machinery & Equipments	3 Electricity and Gas	Final Delivery	Total
1	Fabricated Metal	d_{11}	d_{12}	d_{13}	f_1	x_1
2	Machinery & Equipments	d_{21}	d_{22}	d_{23}	f_2	x_2
3	Electricity & Gas	d_{31}	d_{32}	d_{33}	f_3	x_3
	Added Value	w_1	w_2	w_3		
	Total	x_1	x_2	x_3		

Let:

d_{ij}= deliveries from sector i to j

f_i = final delivery from sector i to the end user

w_i = added value from sector i

x_i = is not only the total deliveries from sector i but also the total input including added value from sector i

n= number of sectors

$j, k = 1, 2, \ldots . n$

Hence:

$$x_i = \sum_{j=1}^{n} d_{ij} + f_i = \sum_{k=1}^{n} d_{ki} + w_i \qquad \text{(Equation 2.1)}$$

The main purpose of input-output analysis in energy assessments is to work out the sectoral energy used directly and indirectly to deliver products that are produced. For example, a consumer construction sector may require a product-for example metal frame from the fabricated metal sector that costs €1 per metre length. A delivery is generated as a result of this in the fabricated metal sector called a zero-order delivery. Because the fabricated metal sector needs materials, energy and services to produce the metal frame, it must purchase these from other sectors. The input-output table is therefore used to determine these indirect deliveries by deriving a technology matrix known as a matrix of direct requirement coefficients. The technology matrix represents the deliveries needed per unit of the total output.

Assuming A is the technology matrix, and a_{ij} the elements of Matrix$A$, Where;

$$a_{ij}=\frac{d_{ij}}{x_i}$$

Where: $A = [a_{ij}]$

Therefore, if the construction industry purchases €1 from the fabricated metal sector, the fabricated metal sector needs to spend d_{11}/x_1 in the fabricated metal sector, d_{21}/x_1 in the Machinery & Equipments sector and d_{31}/x_1 in the electricity and gas sector. These deliveries are the first order deliveries.

The values of first order deliveries are therefore the matrix multiplication of the technology matrix A and the vector $\begin{bmatrix}1\\0\\0\end{bmatrix}$. The vector represents the purchase of 1€ from the fabricated metal sector and is called the extra final delivery represented by ΔF. These orders of deliveries continue infinitely and the second order delivery can be represented by;

$$A.A.\begin{bmatrix}1\\0\\0\end{bmatrix} \text{ or } A.A.\Delta F$$

The total deliveries needed by the fabricated metal sector in order to deliver 1€ of metal frame to the construction sector is therefore the sum of the orders from zero to infinity. That is;

$$\text{Total delivery, T} = (\mathrm{A}^0 + \mathrm{A}^1 + \mathrm{A}^2 + \mathrm{A}^3 + \mathrm{A}^4 \ldots\ldots..) \times \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$= (\mathrm{I} + \mathrm{A} + \mathrm{A}^2 + \mathrm{A}^3 + \mathrm{A}^4 \ldots\ldots..) \times \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

Where Matrix I is the unit diagonal matrix with n rows where, n is the total number of sectors in the economy

From matrix algebra,

$$\mathrm{I} + \mathrm{A} + \mathrm{A}^2 + \mathrm{A}^3 + \mathrm{A}^4 \ldots\ldots.. = (\mathrm{I} - \mathrm{A})^{-1} \qquad \text{(Equation 2.2)}$$

The matrix $(I - A)^{-1}$ is known as the Leontief Inverse Matrix named after Wassily Leontief.

Therefore to determine the extra direct and indirect (cumulative) deliveries needed to produce 1€ of metal frame to be used in the construction sector, the Leontief Inverse Matrix needs to be multiplied by the extra final delivery, ΔF.

Mathematically, this can be expressed as:

$$\Delta \mathrm{x} = (\mathrm{I} - \mathrm{A})^{-1}.\Delta \mathrm{F} = \mathrm{L}.\Delta \mathrm{F}$$

Where:

Δx = the cumulative (direct and indirect) deliveries

L = Leontief matrix

ΔF = extra final deliveries

The total delivery x is however given by;

$$x = (I - A)^{-1}.F = L.F \qquad \text{(Equation 2.3)}$$

Where:

F = column matrix of final delivery.

2.3.2.1 Limitations of Input-Output Embodied Energy and CO_2-eq Analysis

I-O embodied energy encompasses a comprehensive framework but is subject to many inherent errors because of many assumptions made in the analysis. In Chapter 4 of this thesis, some of these limitations of I-O analysis are addressed in the evaluation of the indirect embodied CO_2-eq intensity of Irish construction. Some of the problems associated with I-O analysis are;

i. Product aggregation in sectors
ii. Proportionality Assumption
iii. Homogeneity assumption
iv. Conversion of economic data into physical data
v. Double counting in energy sectors

Some of the limitations addressed in Chapter 4 include the aggregation of different products into one economic sector, double counting of energy inputs in the calculation of embodied CO_2-eq of Irish construction and the conversion of economic data into physical quantities using approaches undertaken with Irish specific derived data.

A. Product aggregation in sector

I-O tables classify the whole economy into different sectors where similar products are aggregated together. For example, all construction activities in the Irish I-O tables are aggregated together as one economic product sector. Hence, a comparative analysis of residential and industrial buildings cannot be undertaken using pure I-O embodied energy and CO_2-eq analysis. This is because the I-O embodied energy and CO_2-eq intensities of both residential and industrial buildings are the same.

B. Proportionality Assumption

The proportionality assumption presumes that the inputs to each sector are proportional to their outputs so that if the output of a sector increases, then the consumption of intermediaries and primary inputs to that sector will also increase proportionally. Hence, it is assumed that energy consumption is directly proportionate to output. For example, the assumption states that if 10GJ of electricity is used to produce one car, then 20GJ would be required to produce two cars. However, economies of scale may act to reduce marginal energy consumption.

C. Homogeneity Assumption

The homogeneity assumption postulates the following:

- each sector produces a single output using identical inputs and processes (that is, all the products of the sector are perfect substitutes for one another or are produced in fixed proportions); and
- There is no substitution between the products of different sectors.

Each industry output is produced using a unique set of inputs which is defined as a unique production function. Since in reality the industry produces a variety of products, it is not possible to achieve complete homogeneity. The homogeneity assumption may be weakened by changes in the product mix and consequent changes in inputs, the introduction of new products or materials. This assumption may be realistic for the year the data is collected but becomes progressively less so in future. Estimates of input changes brought about by technological advances have been accounted for using the latest international data and expert advice.

D. Conversion of economic data into physical data

I-O analysis requires that economic data such as energy tariffs are converted to physical quantities such as GJ, kWh, m^2, m^3, tonnes, etc. Miller *et al.* (1985) notes that national average energy tariffs for instance are not representative across all industries since prices differ due to negotiated energy tariffs in certain industries. As such, the use of average energy tariffs reduces the accuracy of results.

E. Double counting in energy sectors

In I-O tables, a primary energy source such as oil can be classified in a different sector to a different energy sector such as electricity and gas. Since oil is part of the electricity generating fuel mix, that proportion of oil used to generate electricity would be double counted if all energy inputs from each energy supply sector are counted during the analysis.

A comparison between process and I-O embodied energy and CO_2-eq analysis is presented in Table 2.4.

Table 2.4: Summary of the Advantages and Disadvantages of Process and I-O Embodied Energy CO_2-eq Analysis

	Advantages	**Disadvantages**
Process Analysis	Detailed analysis of specific processes More reliable comparison of products Easier identification of process improvements	Subjective system boundary Lack of quality data in most cases Time and cost intensive Uncertainties in data collected
Input-Output Analysis	Comprehensive system boundary defined as whole economy Publicly available data Results can be reproduced	Data is usually aggregated Homogeneity and proportionality assumptions Identification of process improvements is difficult Errors in converting economic data to physical quantities Uncertainties in data collected

2.3.3 Hybrid Embodied Energy and CO_2-eq Analysis

The principal aim of hybrid embodied energy analysis is to combine the advantages of the more accurate process analysis and the extended system boundary of the input-output analysis (Mattila *et al.,* 2010). According to Bilec *et al.* (2006), there are a number of hybrid embodied energy and CO_2-eq analysis methodologies depending on the way process and I-O data are combined. Hybrid embodied energy analysis methodology can be classified as: tiered hybrid, I-O based hybrid, integrated hybrid and augmented process based analysis.

2.3.3.1 Tiered-based Hybrid Analysis

The tiered-based hybrid embodied energy and CO_2-eq analysis was first developed by Bullard *et al.* (1978). The methodology uses I-O analysis in a series of iterative approximations. The first approximation is at the whole economy level where the cost of the product is multiplied by the energy intensity per gross domestic product (GDP). Increasing levels (tiers) of details can be added by specifying parts of the product system to a particular I-O economic sector thereby increasing the specificity of the analysis. In disaggregating the analysis using budget data, parts of the product systems are classified as either typical or atypical. The energy intensity of typical parts can therefore be determined by the associated energy intensity of its I-O sector. The energy intensities of atypical parts of the product system are determined by further disaggregation and the use of iterative I-O approach. The tier-based approach also derives an error term that is supposed to characterise the uncertainty associated with the analysis. The tier-based approach lacks accuracy of product-specific energy intensities because it relies more on I-O data than input-output analysis. The tiered-based approached has also been used in studies by Moriguchi *et al.* (1993) and Munksgaard *et al.* (2000).

2.3.3.2 Input-Output-based Hybrid Analysis

I-O-based hybrid embodied energy and CO_2-eq analysis focuses on disaggregating sectors in the I-O tables using detailed economic information. Three models (Model II, Model III and Model IV) are described as hybrid methodologies by Joshi (2000).

A. Model II:

Model II of the I-O based hybrid analysis described by Joshi (2000) is used when a product being analysed is not typical of an existing I-O economic sector or a completely different product is being introduced into the economy. In the analysis, if the production inputs needed to produce the product and the environmental burdens from the production process are known, then a new hypothetical sector can be inserted into the I-O model to determine the economy-wide economic and environmental effects. Model II assumes that the matrix of direct requirement coefficient or the technology matrix remains unchanged. Bilec *et al.* (2006) explains that this is a major disadvantage in the methodology. Model II is similar to the Tier-based hybrid analysis proposed by Bullard *et al.* (1978) except that process analysis data is included in the analysis thus increasing the amount of product specific data in the analysis.

B. Model III:

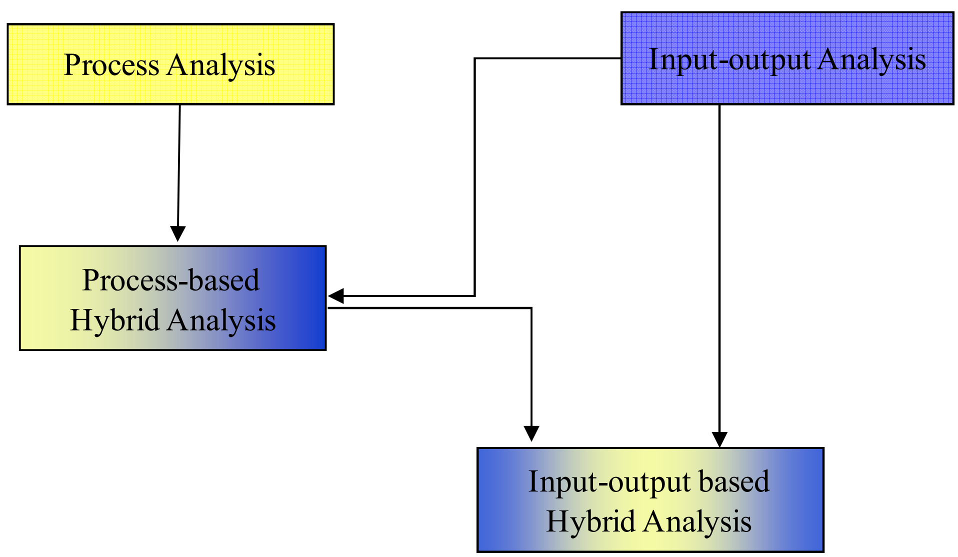
I-O based hybrid embodied energy and CO_2-eq analysis in Model III is undertaken by disaggregating an existing industry sector by the creation of a new technology matrix. This is an improvement on Model II which assumes that the matrix of direct requirement coefficient or the technology matrix remains unchanged. For example, in conducting an embodied energy analysis of road construction, the construction sector can be disaggregated into two sectors namely-'road construction' and 'all other construction'. Assuming the construction sector is represented by sector s then the 'road construction' would be represented by sector $s + 1$. Hence a new $s + 1$ by $s + 1$ technology matrix A with elements A_{ij} has to be derived to represent the same economy which had been represented as a s by s matrix-A, with elements-a_{ij}. According to Bilec *et al.* (2006), the advantages of this approach are that detailed process information can be included without double counting.

C. Model IV

In Model IV, by iteratively disaggregating existing sectors and replacing I-O data for which process data is available, the technology and environmental burden matrices are expanded. It combines the advantages of detailed process information and a comprehensive system boundary of I-O analysis. In cases where inputs for detailed process analysis data are not available, those inputs are approximated by the corresponding I-O sectors which typically would have been excluded from traditional embodied energy and CO_2-eq analysis.

Hybrid embodied CO_2-eq analysis methodologies have also been classified by Treloar (1997) and Crawford (2005) as process-based hybrid analysis and suggesting another form of input-output based hybrid analysis. In Figure 2.3 below, it can be observed that, each of the hybrid models uses data from the process and input-output models. The direction of arrows shows the flow of data between each of the methodologies.

Figure 2.3: Classifications of Hybrid Embodied Energy and CO_2-eq Analysis



2.3.3.3 Process-based Hybrid Analysis

Process-based hybrid analysis incorporates process data into input-output analysis during the calculation of the hybrid energy intensity. Crawford (2005) explains that in calculating the hybrid embodied energy and CO_2-eq intensity for a building, the first step undertaken is to calculate the hybrid energy intensity of the most common basic materials. The hybrid embodied energy and CO_2-eq intensity of the basic material is determined by adding the difference between the I-O total energy intensity of sector n and I-O direct energy intensity of path representing the basic material to the process energy intensity of the material. This input-output difference represents the energy intensity of the material unaccounted for by the process analysis as a result of truncation (or setting the system boundary). The system boundary of a process-based hybrid analysis has similar limitations to those of process analysis, except that the system boundaries for basic material inputs are complete, because of the application of IO-derived total energy intensities. Total energy intensities for materials are translated to physical units by multiplying by average product prices (Bullard *et al.,* 1978). In these cases, a dual pricing error exists, relating firstly to the energy tariffs and, secondly, to the product price. Process-based hybrid embodied CO_2-eq intensities of basic materials are represented mathematically in Equation 2.4 below.

Equation 2.4:

$$\text{Hybrid Embodied } \mathrm{CO}_{2-\mathrm{eq}\ \mathrm{mat}}(\mathrm{HECO}_{2-\mathrm{eq}_{\mathrm{mat}}})$$

$$= \mathrm{PECO}_{2-\mathrm{eq}}\mathrm{I}_{\mathrm{mat}} + \left(\mathrm{TECO}_{2-\mathrm{eq}}\mathrm{I}_{\mathrm{n}} - \mathrm{DECO}_{2-\mathrm{eq}}\mathrm{I}_{\mathrm{mat}}\right) \times \mathrm{Price}_{\mathrm{mat}}$$

Where:

$\mathrm{PECO_2eqI_{mat}}$ = Process embodied CO_2-eq intensity of material

$\mathrm{TECO_2eqI_n}$= I-O total CO_2-eq intensity of sector n

$\mathrm{DECO_2eqI_{mat}}$= I-O direct CO_2-eq intensity of the material energy path

$\mathrm{Price_{mat}}$ = price of the material

The second step is to calculate the direct embodied CO_2-eq intensity ($DECO_2$-eqI) intensity of construction using Equation 2.6 below (Treloar, 1997 and 1998) since data for the more accurate process analysis may not be available.

$$\mathrm{DECO_{2eq}I} = \sum_{e=1}^{E} \mathrm{D_{RC}}\,.\,\mathrm{T_e}.\,\mathrm{PEF} \qquad \text{Equation 2.5}$$

Where:

D_{RC}= Direct requirement coefficients [€/€]

T_e= Average energy tariffs [GJ/€]

PEF= Primary energy factors

Finally, the Process-based Hybrid Embodied CO_2-eq of the building (or product) is calculated using Equation 2.6 below.

Equation 2.6:

$$\text{Process} - \text{based Hybrid Embodied } \mathrm{CO_{2-eq}}$$
$$= \sum_{m=1}^{M} \left(\mathrm{Q_{mat}} \times \mathrm{WF} \times \mathrm{HECO_{2-eq}I_{mat}}\right) + \left(\mathrm{DECO_{2-eq}I} \times \mathrm{Price_{Building}}\right)$$

Where;

Q_{mat}= Quantity of material, m

M= Total number of materials

WF= Waste Factor

2.3.3.4 I-O- based Hybrid Analysis

To further improve the completeness of the embodied energy and CO_2-eq intensities, Crawford (2005) explains that the results obtained from the process-based hybrid analysis can be combined with further I-O values in order to extend the system boundary. To achieve this, the most important energy paths (or processes) of the product are identified and those energy paths whose energy and CO_2-eq intensities have been determined by process analysis are noted. The sum of the direct energy and CO_{2}-eq intensities of materials are determined by input-output analysis and subtracted from the input-output total energy and CO_{2}-eq intensities of the product. The subtraction is done to avoid double-counting. The difference in energy and CO_{2}-eq intensities multiplied by the price of the building (or product) is the additional embodied energy and CO_{2}-eq intensities of the building (or product). To compute the total embodied energy and CO_{2}-eq by I-O hybrid method, this value is then added to the process-based hybrid analysis from which the direct energy and CO_{2}-eq intensities have been subtracted since the direct energy and CO_{2}-eq intensities are already contained in the process-based hybrid value. The advantage of this methodology lies in the extraction of important energy and CO_{2}-eq paths and the completeness of the system framework. Mathematically, the I-O hybrid embodied CO_{2}-eq intensities values can be represented by Equation 2.7 below.

Equation 2.7:

$$\mathrm{I-O-based\ Hybrid\ Embodied\ CO_{2-eq}} =$$

$$\mathrm{Process\ HECO_{2-eq}} + \left[\left(\mathrm{TECO_{2-eq}I_{pdt}} - \sum_{p=1}^{P} \mathrm{DECO_2\ I_{mat}}\right) - \mathrm{DECO_{2-eq}I}\right] \times \mathrm{Price_{pdt}}$$

Where:

$\mathrm{I-O\ HECO_{2-eq}}$ = I-O-based hybrid embodied CO_{2}-eq of the building (or product)

$\mathrm{Process\ HECO_{2-eq}}$ = Process-based hybrid embodied CO_{2}-eq of the building (or product)

$\mathrm{TECO_{2-eq}I_{pdt}}$ = I-O total CO_{2}-eq intensity of product sector

$\mathrm{DECO_{2-eq}I_{mat}}$ = I-O direct energy and CO_2-eq intensity of the energy paths representing collected process data

$\mathrm{DECO_{2-eq}I}$ = Direct energy and CO_2-eq intensity of the product

2.3.3.5 Integrated Hybrid Analysis

Integrated hybrid embodied energy and CO_2-eq analysis described by Suh (2004) combines process and I-O analysis. In this methodology, process-based data are described in the technology matrix with physical units per operation time for each process where as the units for I-O are monetary. The integrated hybrid embodied energy and CO_2-eq analysis is consistent in mathematical framework and avoids double counting but is time and data intensive.

In the integrated hybrid analysis, a matrix representation of process-based analysis is combined with the matrix representation of the input-output analysis.

It has been shown in Equation 2.3 in Section 2.3.2, the total delivery x is given by:

$$\mathrm{x} = (\mathrm{I} - \mathrm{A})^{-1}.\mathrm{f}$$

Given that D_{IM} and $E = \{e_{kj}\}$ are respectively the direct intensity matrix and the environmental extension matrix; where E shows the total emissions emitted to produce the total output of each industry and D_{IM} the sectoral direct emissions intensities derived for GHG emissions, k across j industries. It can be showed that

$$D_{IM} = [E] \times [x']^{-1}$$

Therefore for a given final demand, y, the emission level P' is given by the Leontief allocation to the final demand given by:

$$P' = [D_{IM}] \times (I - A)^{-1} y \qquad \text{(Equation 2.8)}$$

Suh *et al.* (2005) uses Equation 2.7 as the mathematical basis in describing the integrated hybrid embodied energy and CO_2-eq analysis using matrix notation. The integrated hybrid is therefore given by Equation 2.9 below:

Equation 2.9:

$$P' = \begin{bmatrix} E' & 0 \\ 0 & E \end{bmatrix} \begin{bmatrix} P_x' & -D \\ -U & (I - A) \end{bmatrix}^{-1} \begin{bmatrix} y' \\ 0 \end{bmatrix}$$

Where:

P' = Total (direct and indirect) CO_2-eq emissions required to produce the final demand y'

U= Matrix representation of upstream cut-off to the embodied CO_2-eq analysis system

D= Matrix representation of downstream cut-off to the embodied CO_2-eq analysis system

P_x'= Matrix representation of process data

E= Matrix representation of the CO_2-eq emissions of each process

E'= Matrix representation of the CO_2-eq emissions intensity of each economic sector

2.3.3.6 Augmented Hybrid Analysis

Guggemos (2003) employed the augmented methodology in modelling the life cycle of a commercial building. According to Bilec *et al.* (2004), the methodology starts with a process description of the product system. The embodied and CO_2-eq intensities of manufactured materials used are calculated by estimating materials used and their cost.

These are matched to the best-fit I-O economic sectors from which their energy and CO_2-eq intensities are determined. The methodology incorporates a detailed process framework, maintenance of the whole economy as the system boundary and includes missing processes with process models.

2.4 Embodied CO_2-eq Modelling Techniques

Embodied CO_2-eq modelling can either be classified as a deterministic or stochastic modelling framework. A deterministic embodied CO_2-eq intensity is calculated using mean or average data and returns the same results or output for every given input. Stochastic analysis of embodied CO_2-eq intensity on the other hand is undertaken by deriving input probability distributions.

2.4.1 Deterministic Embodied CO_2-eq Modelling

Deterministic embodied CO_2-eq intensity has widely been used in traditional life cycle energy, embodied energy and embodied CO_2-eq calculations (*inter alia* Bullard *et al.* 1978, Munksgaard *et al.,* 2000). The basis of the methodology usually involves using mean or average values in a mathematically derived equation. Suh (2004) for example showed how the life cycle CO_2 emissions for a toaster was estimated to be 18.1kgCO_2-eq calculated using mean or deterministic values from the equation:

$$q' = B'A'^{-1}y'$$

Where:

q'= CO_2-eq environmental impacts of final demand y'

B'= Environmental process matrix

A'= Matrix representation of the physical flows between the processes

The use of these average values in calculating the embodied energy and CO_2-eq intensity of a building would generate the same output or results at all times each time the calculation is undertaken although the average values may contain variabilities. In embodied energy and embodied CO_2-eq calculations, a significant weakness is the incorrect treatment of uncertainties in the input variables (Ciroth *et al.,* 2006) resulting from the use of sparse information and data of unknown quality. The calculations are also undertaken using limited data with unknown reliability of the input data. Variability analysis carried out by Jimenez-Gonzalez *et al.* (2000) for instance showed that the estimated variability in gaseous, aqueous and solid waste emissions are approximately 50–150%, 1000%, and 30% of the mean respectively when the life cycle inventory results for refinery products among several available databases are compared. The wide variations in results are a major limitation in deterministic embodied CO_2-eq calculations.

2.4.2 Stochastic Embodied CO_2-eq Modelling

Stochastic analysis has been applied in ecological and environmental modelling using Bayesian Monte Carlo and Markov Chain Monte Carlo techniques (Bergin *et al.,* 2000; Borsuk *et al.,* 2001). It has also been applied to research into water quality simulation and ground water flow prediction, sea rise prediction and risk assessment. Shih-Chi *et al.* (2005) however believe that the use of Bayesian Monte Carlo method has not been well applied to life cycle assessment. Stochastic analysis has also been applied to CO_2-eq emissions in transportation systems. Research conducted by the Centre for Transportation research, Argonne National Laboratory (2008) involving the development of the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model for LCA analysis of vehicle and fuel systems incorporated stochastic simulations to address parametric uncertainties.

The most comprehensive research on stochastic LCA and embodied CO_2-eq modelling however has been undertaken by Shipworth (2002). In this study, product specific process analysis data is integrated into a stochastic input-output framework through the application of Bayesian statistical techniques. The methodology employs a Markov Chain Monte Carlo (MCMC) numerical method based on the Metropolis-Hastings algorithm which allows for non-normal Bayesian posterior distributions. The MCMC method is employed by drawing dependent random variables from stationary limiting distribution of a suitably constructed Markov Chain. Shipworth (2002) explains that a sample of these random variables is then drawn and used to approximate numerically the integral of the Bayesian posterior distribution of the model's stochastic function to a user determined degree of statistical confidence using the Monte Carlo method. The model requires the construction of a Bayesian model with both prior and posterior distributions. This allows the integration of the more product specific process analysis embodied CO_2-eq data, into the more system boundary complete input-output analysis data. It follows that as the process analysis data is being integrated into the input-output analysis data, the latter is used to form the Bayesian prior distribution, and the former to form the Bayesian posterior distribution.

Shipworth (2002) constructs the Bayesian prior from the disaggregated National Atmospheric Emissions Inventory (NAEI) data underpinning the UK Environmental Accounts (UKENA). According to Vaze (1996 and 1997), the UKENA is compiled to closely reflect the way products are manufactured. This makes it different from the UK Economic I-O tables which are compiled into economic sectors. By employing I-O analysis, meaningful stochastic product specific embodied CO_2-eq data are extracted from UKENA. The matrices of direct requirement coefficients and Leontief inverse matrix which can be obtained from UKENA all convey mean of aggregated data. Shipworth (2002) stated that it is impossible to reconstruct stochastic components using data from a higher level of aggregation. This is because the disaggregated data is of variable quality and consistency across the aggregated I-O sectors.

Shipworth (2002) further explains that in order to construct stochastic data from the disaggregated National Atmospheric Emissions Inventory (NAEI) data underpinning the UKENA, a 220 sector square NAEI I-O matrix is constructed. This is undertaken in a two step process. Firstly, because the UKENA are fully concordant with the UK Standard Industrial Classification 1992 (SIC (92)) the NAEI data underpinning the UKENA is disaggregated to the three digit SIC(92) level resulting in a 220 sector square NAEI I-O matrix. Each sector of the UKENA will then have a variable number of SIC (92) concordant subsectors. This will create 922 UKENA sub-sectorial transaction matrices of varying size. The NAEI data currently aggregated to the UKENA 92 sector level is then disaggregated to form row and column totals at the newly created subsector level. The second part of the process involves using the generalized maximum entropy principle

(Golan *et al.*, 1996) to reconstruct the inter-subsectorial transaction data from the row and column totals provided by the disaggregated NAEI data. The generalized maximum entropy principle permits a hypothesized reconstruction of missing data from ill-poised underdetermined stochastic models consistent with the information-theoretic maximum entropy principle of Shannon (1948). The data is reconstructed along with a measure of its uncertainty. The generalized maximum entropy principle and the generalized cross entropy principle stem from information theory and statistical physics but are seeing increasing use in econometrics in situations such as these where the base data is limited. It has been explicitly used for the reconstruction of missing direct inter-sectoral transaction I-O data such as in this case (Golan *et al.*, 1996). Shipworth (2002) explains that the reconstruction of a 220 NAEI sector direct I-O matrix will permit construction of a set of simulated material supply chains within the construction sector as defined at the 91 sector UKENA direct I-O matrix. CO_2-eq is embodied in materials at each step along the supply chain, from raw material extraction, to point of entry to the construction sector (as defined at the UKENA 91 sector level).

Shipworth (2002) further states that process analysis data is used to define the posterior distribution and it is integrated into the I-O data using Bayes' rule. The process analysis data is sourced from academic publications and construction sector material supply organizatons. The Bayesian posterior is then simulated using the MCMC method. Samples can are drawn from the posterior distribution using Markov chains and cumulative CO_2-eq for given materials determined using Monte Carlo analysis. This integration gives a distribution for final CO_2-eq for selected materials based on I-O data that has been updated using process analysis data. The model can be continuously refined through progressive integration of further process analysis data.

The stochastic model developed by Shipworth (2002) suffers from well established limitations such as the homogeneity and proportionality assumptions of I-O data and truncation of the system boundary of process analysis data. In countries without National Atmospheric Emissions Inventories (NAEI), this model cannot be implemented. The model developed by Shipworth (2002) employs the Markov Chain Monte Carlo method and the generalized maximum entropy method. These represent significant high degree of analytical challenges.

2.5 Treatment of Uncertainties in Embodied CO_2-eq Analysis

Uncertainties of embodied CO_2-eq analysis refers to the fact that calculated values frequently do not match the true values, but differ from them in a probabilistic manner (Ciroth 2004). Hence, uncertainties can be described as probabilistic errors of quantitative values. Uncertainties calculations are carried out in order to allow the user to appreciate the significance of data and results. Embodied energy and CO_2-eq analysis have been used as a decision support tool in the comparison of design and product alternatives in many instances (FAO, 2002 and Valkama *et al.,* 2008). According to Cowell *et al.* (2002) the differences in the environmental impacts may be misleading if uncertainties in these impacts are large enough to dominate any differences between the alternative designs. Quantification of these uncertainties therefore supports informed decision making. Further advantages of tackling uncertainty in embodied energy and CO_2-eq analysis are outlined below.

A. Improving quality

Uncertainty is commonly seen as an indicator of data quality (Weidema *et al.,* 1998 and Huijbregts, 2001), hence reduced uncertainty such as in LCA databases is therefore desirable. By transparently displaying uncertainties there will be increased motivation to improve data quality both for general data and individual case studies (Ciroth 2003).

B. Planning and Prioritizing

By understanding the kind of uncertainties that exist in a model and the uncertainties that have the greatest impact on results, data collection can be prioritized. This helps to use time and resources on data collection efficiently.

C. Increase credibility of results

Weidemer (2000) reported that if model inputs are uncertain and the uncertainty is hidden or ignored in calculations, then it lowers the credibility of the embodied energy and CO_2-eq analysis. For instance, if an alternative valid model inputs are proposed leading to different outputs, without acknowledging the uncertainties leading to both sets of model inputs being plausible, there is no clear resolution to both scenarios, hence reducing the credibility of the results.

2.5.1 Types of uncertainty

The US EPA (1989) classified uncertainties that can be applied to embodied energy and CO_2-eq analysis as parameter uncertainty, scenario uncertainty and model uncertainty.

2.5.1.1 Parameter Uncertainty

Incomplete knowledge of the true value of data and measurement error in input values are the main sources of parameter uncertainty. Incomplete knowledge of data may arise because of the following (Huijbregts *et al.,* 2001):

- data for which no value is available
- data for which an unsuitable value is available
- data for which more than one value is available

Parameter uncertainty in LCA can be dealt with using techniques such as analytical propagation methods, stochastic models, fuzzy logic and neural networks.

2.5.1.2 Model Uncertainty

Model uncertainty may arise due to unknown interactions among model parameters. A lack of knowledge of the functioning of the system can also cause model uncertainty (Asbjomsen, 1995). Model uncertainty may also arise due to simplifications of aspects that cannot be modelled within the embodied energy and CO_2-eq analysis structure such as temporal and spatial characteristics lost by aggregation, non-linear instead of linear models, or derivation of characterisation factors (Huijbregts, 1998). According to Porta *et al.* (2007), very few studies include such analysis and discuss strategies for identifying model uncertainties that are important contributors to the overall uncertainty. Huijbregts *et al.*

(2003) for example quantified model uncertainty by re-sampling different model formulations. In a recent study by William (2007), it stated that the combination of input-output analysis and process techniques in embodied energy and CO_2-eq analysis can mitigate model uncertainties.

2.5.1.3 Scenario Uncertainty

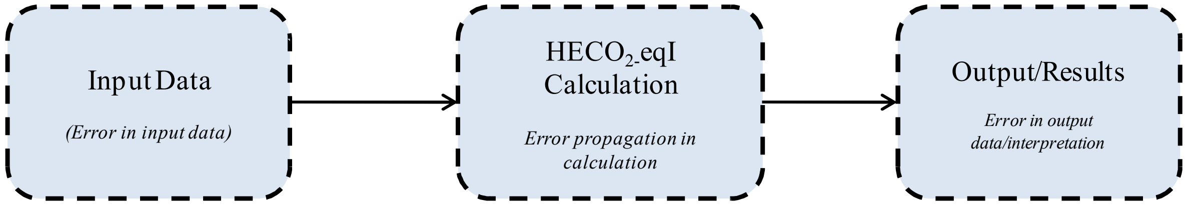
Scenario uncertainties arise due to choices regarding functional unit, system boundaries, weighting of factors and forecasting, etc. Huijbregts *et al.* (2003) suggested quantifying scenario uncertainty by re-sampling different decision scenarios. For example, results can be calculated for a data set with high emission values and a data set with low emission values.

2.5.2 Other Uncertainty Classifications

Theoretically, the uncertainty in embodied energy and CO_2-eq analysis can also be viewed as a simple input and output box as represented in Figure 2.4. Ciroth *et al.* (2004) explained that the problems associated with uncertainty can be classed as three sub problems namely:

- Problem 1: Assessing errors in input data;
- Problem 2: Assessing the propagation of errors in the calculation;
- Problem 3: Assessing errors in the calculation's outcome, interpreting outcomes with inherent errors and uncertainties

Figure 2.4: An input and output classification of uncertainties



Adapted from Ciroth *et al* (2004)

2.5.2.1 Input Uncertainties

Various authors have attempted to deal with input uncertainties in LCA and embodied energy and CO_2-eq analysis. Copius Peereboom *et al.* (1999) for example, varied one input parameter while keeping the rest constant at their most probable value. The process is repeated for all other input parameters in separate analysis. Geodkoop *et al.* (2004) on the other hand defined a limited number of scenarios with specific but consistent realizations of each input parameter. Sampling methods in the form of Monte Carlo analysis can also be used to model input parameters (Shipworth 2002).

2.5.2.2 Output Uncertainties

The output or results can be presented using tables and graphs for the different sets of parameters. Results of the sampling technique can be presented in two main forms. Firstly, using graphs such as histogram or probability density plots. Secondly, a graphical representation can be used to indicate the average value and two boundary values-the upper boundary being the for example the 95^{th} percentile and the lower boundary the 5^{th} percentile. Uncertainty analysis results of analytical methods are given as moments of the distribution (such as standard deviation) and do not provide graphical distributions as outcomes.

2.5.3 Quantifying and Processing Uncertainties in Embodied CO_2-eq Analysis

A number of techniques exist in quantifying and processing uncertainties in LCA and embodied energy and CO_2-eq analysis. According to Heijungs *et al*. (2004) they can be classified as:

- parameter variation/scenario analysis;
- sampling methods;
- analytical methods;
- non-traditional methods, such as the use of fuzzy set theory.

2.5.3.1 Parameter Variation/Scenario Analysis

This technique involves investigating what effects different sets of data, models and choices have on the results. For example, in an analysis of parameter variation in embodied energy and CO_2-eq analysis of a building, the effects of high and low process embodied CO_2-eq intensities of building materials on the results may be examined. Peereboom *et al.,* (1999) for example used parameter uncertainty to investigate the influence of inventory data sets on life cycle assessment results using PVC as a case study.

2.5.3.2 Sampling Method

The sampling technique of uncertainty analysis is based on iterative calculations with the input data drawn from distributions such that the results differ from run-to-run. The statistical properties of the sampling results can then be analysed. A well established sampling technique is the Monte Carlo analysis. Maurice *et al.* (2000) has applied Monte Carlo analysis to life cycle analysis of electricity generation of power plants, Sonnemann *et al.* (2003) to life cycle analysis of electricity generation of waste incinerators and Shipworth (2002) to embodied greenhouse gas emissions in construction materials.

2.5.3.3 Analytical Method

Heijungs *et al.* (2002) used the analytical method based on the first order approximation of the Taylor expansion of the underlying model which is expressed as an explicit mathematical equation. In this approach, the variance (or standard deviations) of the input parameters are used to calculate the variance (or standard deviations) of the outputs.

2.5.3.4 Non-Traditional Methods

Non-traditional statistical approaches such as Bayesian analysis, fuzzy logic, neural networks and non-parametric statistics can be used to deal with uncertainty analysis in life cycle and embodied CO_2-eq analysis. Rong *et al.* (1998) and Weckenmann *et al.* (2001) have incorporated fuzzy logic in life cycle assessments while Shipworth (2002) has used Bayesian analysis to model embodied greenhouse gas emissions.

2.5.4 Quantifying Uncertainty using Stochastic Analysis

In this study, the stochastically derived hybrid embodied CO_2-eq intensities are used as the basis for estimating uncertainties in the CO_2-eq embodied in buildings. As has been shown by Ciroth *et al.* (2004), in the linear input and output classification of uncertainty in LCA calculations described in Section 2.6.2, errors in input data are propagated within the model then incorporated in the output or results. By using this principle within a Monte Carlo stochastic framework, uncertainties of stochastic input variables are propagated within the model after many simulations and then evaluated from the output of the stochastic model. It is shown in Chapter 5 how uncertainty in the CO_2-eq embodied in the apartment building sector in Ireland is estimated from stochastically derived output distribution.

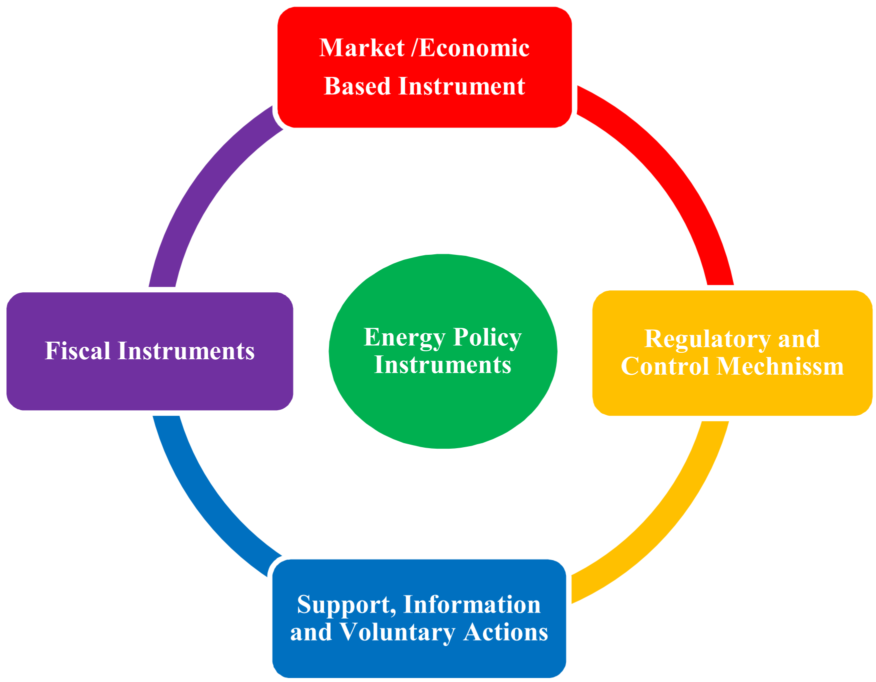
2.6 Building Sector Energy and Emissions Policies

Energy and emissions policies in the building and construction sector have traditional focussed on the operational phase of a building and usually involve renewable energy supply (RES) and energy efficient measures. According to a report by the IPCC (2007a), measures to reduce greenhouse gas emissions from buildings fall into one of three categories: reducing energy consumption and the embodied energy in buildings; switching to low-carbon fuels including a higher share of renewable energy; and controlling the emissions of non-CO_2 greenhouse gases.

The International Energy Agency (2003) has reported that without existing policy measures such as energy labelling, voluntary agreements and minimum energy efficiency performance standards, electricity consumption in OECD countries in 2020 would be about 12% higher than if they were not implemented. Given the absence of effective policies directly targeted at embodied emissions in buildings, the provision could help to reduce the overall GHG emissions from buildings and meet policy targets.

The IPCC (2007a) identifies key building sector policy instruments, grouping them into four major categories. These are represented in the radial cycle in Figure 2.6 below.

Figure 2.5: Classification of Building Sector Energy and Emissions Policies



Adapted from IPCC (2007a)

In the review report produced by IPCC (2007a), it was established that all the groups of energy policy instruments can achieve significant energy and CO_2 savings; however appliance standard, building code, labelling and tax exemption policies achieved the highest CO_2 emission reductions. The report also found out that labelling and voluntary programme can lead to large savings at low-cost if they are combined with other policy instruments while information programmes can also achieve significant savings and should accompany most other policy measures to enhance their effectiveness.

The IEA (2004) also reported that although many new policies have been initiated in the last decade, energy consumption by buildings is still increasing. However, in a review of 20 of the most important policy tools (IPCC, 2007a), no specific policy instrument was found that directly measures the impact of embodied energy or embodied emissions, despite being identified as one of the three main areas needed for GHG reduction in the building sector.

This section of the literature reviews the four main groups of energy and emissions policies for the built environment and concludes by describing how evidence-based policies can be developed using stochastic embodied CO_2-eq intensity analysis. As stated previously, the main energy and emissions policies can be characterised as follows:

i. **Regulatory and Control Mechanisms**: These are laws that require certain actions to be taken, device or control systems installed or practices adhered to. Regulatory and control mechanisms can either be a normative policy such as building codes and appliance standards or informative policy which includes mandatory labelling and certification and mandatory audits.

ii. **Economic or Market-based Instruments**: Market Based Instruments are policy delivery tools that use market-like approaches to positively influence the behaviour of people. These policy instruments may require voluntary participation but are initiated by regulatory incentive. These include Kyoto Mechanisms and the Emission Trading Scheme.

iii. **Fiscal Instruments and incentive**: These are policies that reward stakeholders and consumers through tax breaks, grants, etc. for implementing measures that reduce energy consumption and CO_2 emissions. These include taxation and capital subsidies and grants.

iv. **Support, Information and Voluntary Actions**: These policies are implemented to encourage behavioural change by providing information to stakeholders and consumers. Support, Information and Voluntary policies can include voluntary certification and labelling as well as education and informational campaigns.

2.6.1 Regulatory and Control Mechanisms

Regulatory and control mechanisms are the most common policy tools used in the building industry (UNEP, 2007). The OECD (1989) explained that regulatory and control mechanisms are institutional rules which are formulated to directly influence the environmental performance of polluters either by regulating processes and products being used or by limiting the discharge of certain pollutants (or emissions) or restricting certain activities to certain areas or periods in time. It has been shown that regulatory standards have worked well in the building sector if enforcement can be secured. However, if they are not properly applied they become ineffective tools (Deringer *et al.*, 2004). It has been shown that regulatory mechanisms are generally more effectively enforced in new buildings than in existing buildings (EURIMA, 2006). Other issues that need to be addressed in regulatory and control mechanisms in buildings are low income households which may not be able to afford the measures required to improve the energy performance of their buildings.

2.6.1.1 Normative: Appliance Standard

Building sector appliance standards are instruments used to increase the energy performance of appliances used generally in residential and commercial buildings by setting specific minimum energy efficiency requirements (Nadel, 2002). These standards are among the oldest and commonly used instruments for increasing energy efficiency in buildings (Mahlia *et al.*, 2002). The US was among the first countries to implement appliance standards. According to Geller *et al.* (2006), the implementation of these standards has resulted in the decrease of the US national annual electricity demand by 2.5% in 2000 when compared to the projected demand and it is further expected to achieve a reduction of 7.8% by 2020. The IEA (2003) projects that, in 2020 the net benefit of appliance standard is estimated to be \$65/tCO_2 in the US and €169/tCO_2 in Europe. Standards have been set for more than 35 products, with household goods such as refrigerators, air conditioners and freezers and ballasts being the most common. Based on the available evidence, standards appear to be a very effective energy-saving policy. They have reduced energy use substantially in the United States and made good initial progress in other countries (Nadel 2002). Harrington *et al.* (1997) also reported that recognition of energy labels among randomly surveyed adults is consistently above 65% throughout Australia and that energy labelling of appliances has risen as a consumer priority, with about 30% considering energy efficiency rating to be the most important factor when purchasing new appliances.

2.6.1.2 Normative: Building Codes

These are standards that address the energy use of an entire building or building system (Birner *et al.*, 2002) and are one of the most commonly used instruments to improve the energy efficiency of a building. Building codes exist in most developed countries. In the EU, national building codes are required under the Energy Performance of Buildings Directive (EPBD – 2002/91/EC) which aims to reduce operational energy and GHG emissions in the building sector. This is similar to the Australian Building Code, the Buildings' Sustainability Index (BASIX) certification and Japan's Energy Conservation Law, all of which provide information on the energy performance of buildings. Building designers are familiar with direct regulation targeted at the building and construction sector to improve the energy performance and efficiency of the building.

2.6.1.3 Informative: Mandatory Labelling and Certifications

Policy instruments that require the mandatory provision of information to users about the energy performance of a product-such as a building or electrical appliances- are mandatory certification and labelling policies. According to Perez-Lombard (2009) energy certification schemes for buildings emerged in the early 1990s as an essential method for improving energy efficiency, minimising energy consumption and enabling greater transparency with regards to the use of energy in buildings. Mandatory certification and labelling policies of buildings are generally considered to be one of the most effective and cost effective policy instruments which can be used to achieve the required savings in buildings (ASHRAE, 2008).

In the EU, building energy certification and labelling has developed rapidly in recent years with the implementation of the recast Energy Performance of Buildings Directive (EPBD)

(2002/91/EC). The Directive on energy performance of buildings (2002/91/EC) is the main legislative instrument at the EU level to achieve energy performance in buildings (European Commission, 2003). This, however, is for operational energy use by buildings and ignores embodied energy and emissions of the building. It stipulates not only the energy assessment and certification of new and existing buildings but also the prominent display of the energy rating certificate of the building. In Ireland this policy is implemented through the provision of a Building Energy Rating (BER) Certificate. The BER is an indication of the energy performance of a specific dwelling. It covers energy use for space heating, water heating, ventilation and lighting, calculated on the basis of standard occupancy. A-rated properties are the most energy efficient and are expected to have the lowest energy bills. Mandatory labelling of buildings are more expensive than appliance labelling since assessments must be carried out for each building individually before an energy rating certificate is issued. The European Committee for Standardization (CEN) (European Committee for Standardization, 2010) which specifies standards for the EU community currently has under approval a standard for the Sustainability of Construction Works - Assessment of Buildings, CEN/prEN 15643.

2.6.1.4 Informative: Mandatory Audits

These are compulsory energy audit programs usually targeted at industrial units but rarely undertaken for residential housing. Mandatory audit programs are combined with other instruments such as financial incentives to enhance their effectiveness (World Energy Council, 2004). They have the advantage of ensuring rapid energy savings since many large commercial and industrial units can be targeted simultaneously at the same time especially in times of energy shortages, however they requires qualified audit personnel (Eichhammer

2007). The success of mandatory energy audits depends on the implementation and financing of proposed retrofits required to cut down energy usage.

2.6.2 Economic or Market based Instruments

These are based on market mechanisms and may contain elements of voluntary action initiated by regulatory incentives. The Kyoto Flexibility Mechanism is one such economic or market based instrument. According to Novikova *et al.* (2006) the Clean Development Mechanisms is one such Kyoto Flexibility Mechanism in the building sector. This is designed as a cost-effective instrument for delivering financing, know-how, sustainability benefits as well as capacity building for GHG mitigation projects in developing countries and economies in transition as well as in the buildings sector. Building are known to have the highest cost-effective potential for carbon savings compared to other sectors (IPCC, 2007a), hence it is expected that this policy would deliver significant energy savings during the 1st Kyoto commitment period which runs from 2008-2012.

Among the energy and emissions policies instituted by the EU to control GHG are market-based instruments which generate economic incentives to invest in technologies with the lowest marginal emissions abatement costs. For example, the EU Greenhouse Gas Emissions Trading Directive System (EU ETS) was introduced to achieve average GHG emissions reductions of 8% below 1990 levels by 2012 for EU-15 member states (OpenEurope, 2007). The scheme, which works on a 'Cap and Trade' basis, is the largest multi-country, multi-sector GHG ETS world-wide where participants must buy and sell allowances. EU governments set emission caps for all installations such as energy and industrial plants covered by the scheme for the particular commitment period. The number of allowances allocated to each installation for any given period is determined on the basis of the National Allocation Plan. The ETS has an impact on emissions in the construction sector because it covers many large suppliers to the construction sector such as energy producers, cement manufacturers and the steel industry. For example, with the four cement factories in Ireland accounting for 5% of total national emissions in 2005 (Walker *et al.,* 2009), 11% of the national allowance has been allocated to the cement sector (Irish EPA, 2008). In Germany, between 2005 and 2007, 495 million tCO_2 was allocated per annum with 23.73million tCO_2/a (or 4.8%) allocated to the cement industry and 33.69million tCO_2 (or 6.8%) allocated to the Iron and Steel industry (DEHst, 2008). By incentivising CO_{2}-eq mitigation, the ETS helps to reduce the embodied emissions intensity in the building and construction sector by reducing indirect emissions from large polluters in the supply chain.

2.6.3 Fiscal Instruments and Incentives

These are policy tools which influence energy prices by imposing taxes with the objective of reducing energy consumption by consumers. It is generally seen as a fair form of policy instrument since it imposes a uniform tax to the whole economy. However, economic and social challenges such as fuel-poverty may affect the vulnerable in society.

2.6.3.1 Carbon Tax

Carbon tax is an indirect tax that sets a price for carbon dioxide emissions and is based on the Polluter Pays Principle. Carbon tax has been in place since the early 1990's in some EU member states including Sweden, Denmark, Netherland, Norway and the UK. In Ireland a carbon tax of €20 per tonne of carbon emitted will been introduced in 2010. Critics of carbon taxes have argued that their introduction in other jurisdictions has not generally seen a reduction in emissions (Barazini 2000 and Bruvoll *et al.,* 2003). It is true that carbon taxation is particularly ineffective for goods or services with low elasticity of demand - such as the transport sector - where fuel price increases do not significantly reduce private car use (Litman, 2009). With regard to embodied emissions in structures and buildings, a carbon tax is unlikely to have a short-term impact on many direct emissions (example, through the use of construction plants) because there are few options for technology switching.

2.6.3.2 Subsidies

Subsidies provide incentives for favoured technologies or practices and can be classified as direct or indirect. An example of a direct subsidy is the biofuel GAYA project in France, (EUROPA, 2010) which aims at developing production technologies for second-generation motor biofuels. Subsidies for PV systems have also resulted in market growth mainly in Germany and Japan (Sandén, 2003). Grants are also provided through the Greener Home Scheme in Ireland to encourage the retro-fitting of older homes with energy saving insulation and control systems and home renewable heating systems. The UK's Renewable Obligation and the Climate Change Levy (Renewable Energy Foundation, 2008) are examples of indirect subsidies: in the former a Renewable Obligation Certificate (ROC) is issued to electricity generators designed to incentivise renewable generation in the electricity generation market; the latter is a tax on delivered energy to non-domestic users aimed at providing an incentive to increase energy efficiency and to reduce CO_2 emissions.

While direct subsidies are easier to monitor and quantify, indirect subsidies may have a more significant impact. Legge *et al* (2009) asserts that carefully designed subsidies can succeed in reducing greenhouse gas emissions if set in the right policy mix, but because they need to be so carefully designed, they are prone to lead to unintended or suboptimal outcomes. Hence, unless a way is found to award subsidies based accurately on the marginal cost of carbon abated, they may prove to be an ineffective and expensive way to reduce emissions. Policies on embodied emissions therefore need to be developed in order to establish a link between the potential to reduce embodied carbon and the award of subsidies.

2.6.4 Support, Information and Voluntary Actions

Support, Informational and Voluntary Action policies are policy tools that are largely voluntary programs that provide consumers with environmental information (Rotherham 1999). They provide consumers an indication of the overall environmental preference of a specific product compared with others within the same product category. According to (Gillingham *et al.*, 2006), the US Energy Star Program is one of the best known and successful voluntary labelling programs are expected to reduce annual carbon emissions by 3.5% relative to what they would have been in the absence of these programs. Buildings qualify for an Energy Star if they achieve a rating of 75 or greater on a scale of 0-100 relative to similar buildings based on the US EPA's standards. Menanteau (2001) reports that voluntary certification and/or labelling systems have also been developed for building products such as windows, insulation materials and HVAC components in North America, the EU and other countries. The voluntary certification of buildings has proved to be effective in ensuring compliance with energy codes and sometimes even leads to achieving higher performance standards (Hicks *et al.,* 1999). This is because consumers have become more knowledgeable about environmental issues and the demand for “green” goods, hence responsible companies have risen proportionally (Salzman, 1991). Some problems identified with voluntary labelling are that inefficient products are often not labelled, a lack of government commitment and insufficient testing centres. Completely voluntary programs can become more effective when combined with other instruments. The threat of regulation can also increase their effectiveness (Geller *et al.,* 2006). Voluntary instruments can vary in their effectiveness because it depends on the demand for energy efficient products and on whether the companies take their voluntary commitments serious.

2.6.4.1 Information: Eco-labelling

A number of voluntary measures for reducing embodied CO_2 and life cycle emissions using life cycle assessment (LCA) methodologies exist. The Eco-labelling initiative employs an LCA methodology and is widely deployed around the world. An ‘Eco-label’ is a label which identifies the overall environmental performance of a product or service within a specific product/service category based on life cycle considerations (Ball, 2002). Schenck (2006) shows that life cycle assessments undertaken in the manner outlined in ISO 14040 have formed the basis for many laws in Europe including: the 2002 Restriction on the use of Certain Hazardous Substances in Electrical and Electronic Equipment; 2003 Integrated Product Policy; 2004 EU Directive on Packaging & packaging waste; and 2005 Waste Electrical and Electronic Equipment (WEEE). However, no such embodied energy and CO_2-eq regulations exist for the building sector even though embodied emissions in this sector can be a significant part of the total product life cycle emissions. Voluntary eco-labelling schemes has however been specifically designed for the building and construction sector in a variety of countries. These include the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED), the UK's BRE Environmental Assessment Method (BREEAM) and the Hong Kong Building Environmental Assessment Method (HKBEAM). BREEAM for instance considers a wide range of environmental impacts such as: global warming due to energy use and CO_2 emissions, resource consumption due to material use; land fill due to waste production; and reduction in biodiversity due to land take and pollution.

2.6.5 Evidence-based Embodied CO_2-eq Policies

Given that specific embodied CO_2-eq based regulations do not exist for the building and construction sector, it is shown in Chapter 6 how stochastic embodied CO_2-eq distributions are used as the basis for evidence-based emissions policy formulations. The stochastic distributions are also used to estimate potential savings in embodied emissions from buildings. Such evidence-based policies are needed if embodied CO_2-eq is to complement other building sector policies discussed above.

CHAPTER 3: Research Methodologies

3.0 Overview

The methodologies used in the thesis are broken down into three sections and are implemented to achieve the objectives outlined in Section 1.1. In summary, it involves:

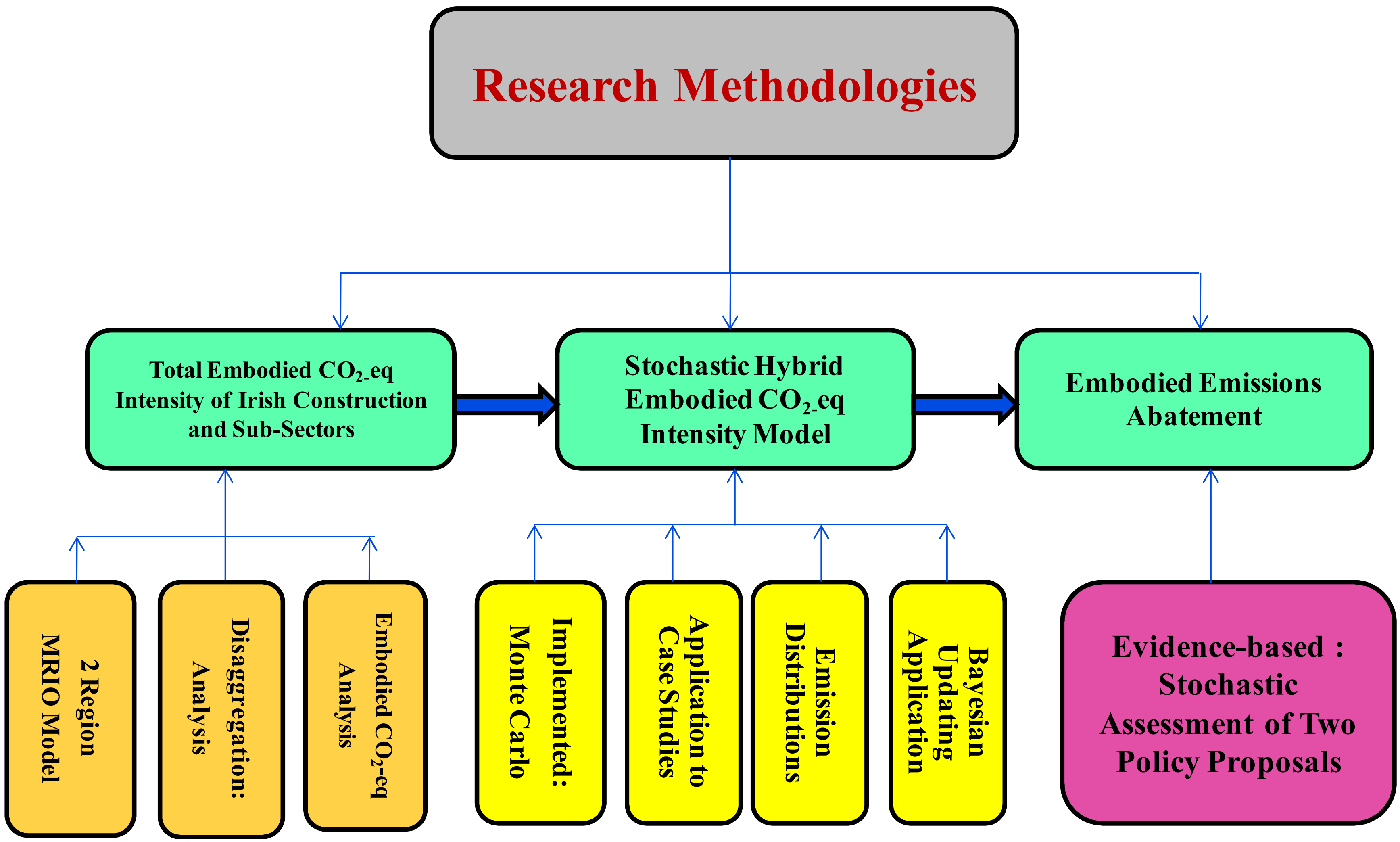
i. An evaluation of the total embodied CO_2-eq intensity of Irish construction and construction sub-sectors by deriving sub-sectoral direct embodied CO_2-eq intensities and sectoral I-O embodied CO_2-eq intensities incorporating input-output tables (direct requirement coefficient and Leontief inverse matrix) re-derivation, derived disaggregation constants (to disaggregate I-O energy supply sectors and avoid double counting of energy inputs) and construction sub-sectoral analysis

ii. A stochastic application to hybrid (integration of process and input-output analysis) embodied CO_2-eq intensity relationship employed using Monte Carlo technique and applied to the apartment building sector in Ireland. Hybrid Embodied CO_2-eq Intensity (HECO_2-eqI) distributions are derived for the apartment building sector.

iii. Identification and testing of possible emissions policies using stochastic distributions

The methodologies are further explained below and illustrated in Figure 3.1 below.

Figure 3.1: Research Methodology



3.1 Methodology used in Calculating Total Embodied Energy and CO_2-eq Intensity of Irish Construction and Irish Construction Sub-Sectors at Disaggregated Level

The methodology used to calculate the energy and CO_2-eq embodied in Irish construction and Irish construction sub-sectors is presented below. The methodology combines sectoral input-output analysis data and construction sub-sectoral analysis data derived from economic data of energy used by construction firms in Ireland. It involves the following steps:

i. The Irish construction sector is divided into five sub-sectors (NACE 45.1 to NACE 45.5) as defined by the NACE classification system in the European System of Accounts. These are further explained in Section 4.1

ii. The direct embodied energy intensity in GJ/€ of each of the five sub-sectors of construction termed sub-sectoral direct embodied energy intensity is evaluated for the years 2003, 2004, 2005 and 2006 using the census data of the building and construction industry conducted in Ireland (Central Statistics Office, 2005; 2006; 2007 and 2008a), primary energy factors (Sustainable Energy Authority of Ireland, 2007) and average energy tariffs (Sustainable Energy Authority of Ireland, 2009). As further explained in Sections 4.1, the average direct embodied energy intensity is calculated as a weighted average of the output for each of the sub-sectors and over the years 2003-2006.

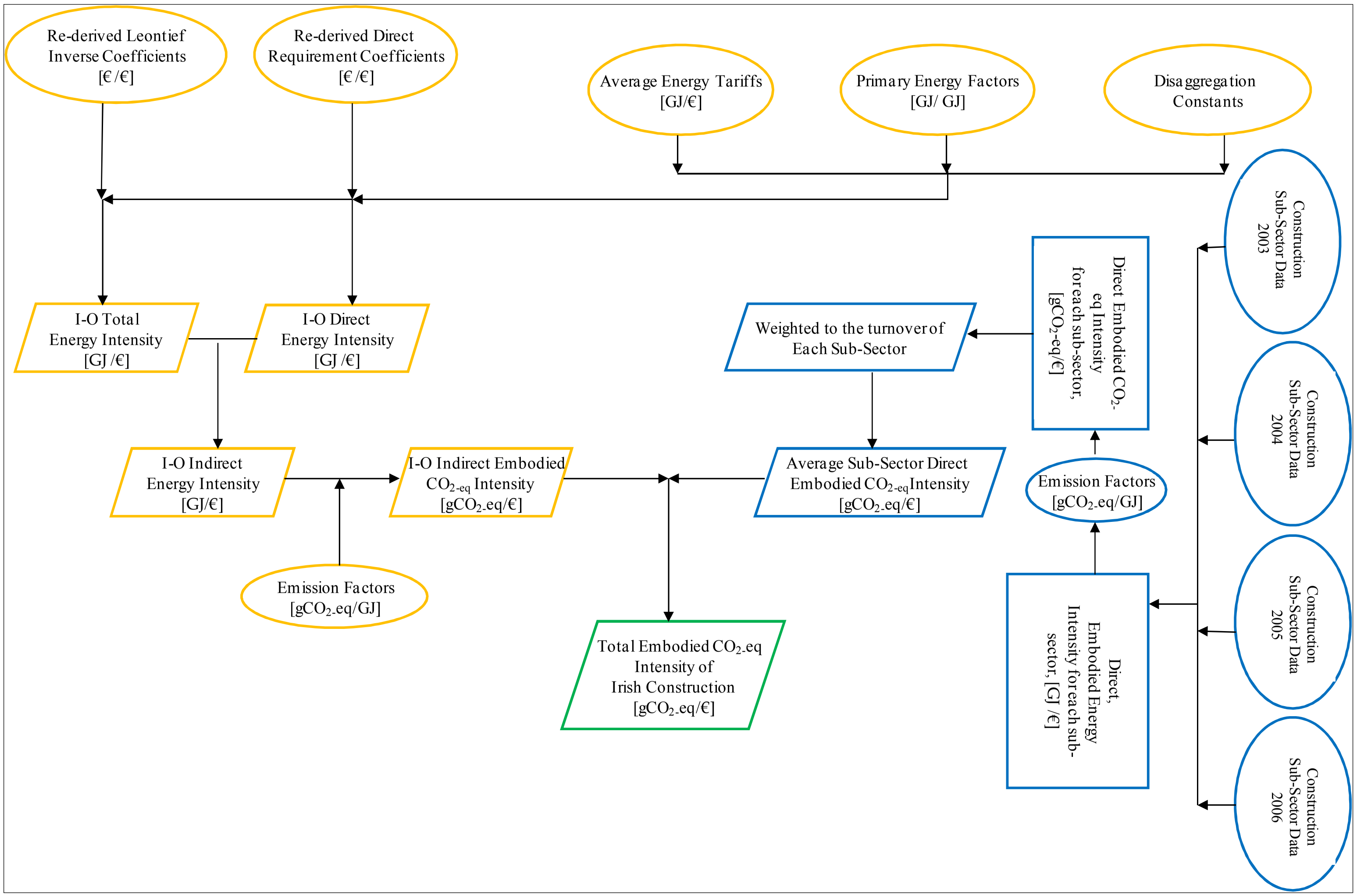
iii. For the derivation of embodied CO_2-eq intensities, the sub-sectoral direct energy intensity is converted to sub-sectoral direct CO_2-eq intensity using national emission factors published by Sustainable Energy Authority of Ireland (2003).

iv. The direct and total I-O sectoral embodied energy intensities of construction as shown in Section 4.4 are calculated using the re-derived I-O matrices from the Irish I-O tables (Central Statistics Office, 2009b), primary energy factors (Sustainable Energy Authority of Ireland, 2007) and average energy tariffs (Sustainable Energy Authority of Ireland, 2009). The I-O matrices of direct requirement coefficient and the Leontief inverse matrix for Ireland are re-derived to take into account goods and services imported into Ireland. The analysis is shown in Section 4.3.1. This is undertaken by assuming the product technology assumption which states that each product is produced in its own specific way irrespective of the industry where it is produced. The indirect I-O sectoral embodied energy intensity of construction is then calculated as a difference of the total I-O sectoral embodied energy intensity and the direct I-O sectoral embodied energy intensity incorporating the use of disaggregation constants which are also shown in Section 4.4.

v. For the analysis of embodied CO_2-eq, I-O indirect embodied energy intensity is converted to I-O indirect embodied CO_2-eq intensity using national emission factors published by Sustainable Energy Authority of Ireland (2003).

vi. The total embodied CO_2-eq intensity of Irish construction is calculated as the sum of the I-O sectoral indirect embodied CO_2-eq intensity and the weighted direct sub-sector embodied CO_2-eq intensity. The total embodied CO_2-eq intensity of the construction sub-sectors are also calculated as the sum of the proportion (using the ratio of sub-sector output) of the I-O sectoral indirect embodied CO_2-eq intensity and the direct sub-sectoral embodied CO_2-eq intensities of each sub-sector.

Figure 3.2: Flow Diagram of I-O and Sub-Sectoral Analyses of Embodied Energy and CO_2-eq Intensity of Construction



3.2 Stochastic Hybrid Embodied CO_2-eq Intensity (HECO_2-eqI) Methodology

The Hybrid Embodied CO_2-eq Intensity (HECO_2-eqI) framework is developed combining input-output and process methodologies in order to derive the benefits of both methodologies. Estimating HECO_2-eqI using a hybrid approach involves combining a variety of data. Process analysis is used to determine the CO_2-eq embodied in the main building materials of the buildings, construction sub-sector analysis to derive the direct CO_2-eq emitted on site in constructing the buildings and input-output analysis to estimate the sectoral and upstream indirect CO_2-eq emitted.

A model HECO_2-eqI relationship which can be broken down into three parts and expressed in terms of total embodied CO_2-eq [gCO_2-eq] per Euro [€] output of total expenditure is developed and forms the basis for the stochastic analysis. Stochastic HECO_2-eqI of buildings was implemented using Monte Carlo techniques resulting in the generation of probabilistic HECO_2-eqI outputs with the uncertainties in stochastic input parameters captured in the analysis. The methodology adopted involves:

i. The use of hybrid analysis to develop mathematical relationships between input parameters such as product emissions intensities, input-output sectoral emissions intensities, disaggregated construction emissions intensities, construction materials employed and construction expenditure;
ii. A stochastic HECO_2-eqI analysis was carried out by deriving probabilistic input distributions for all the stochastic input variables for which data is available, namely: the process embodied CO_2-eq of all building materials (Sustainable Energy Research Group, 2008) and the direct embodied CO_2-eq intensity of the disaggregated five sub-sectors of Irish construction.

iii. An analysis of industry (process) data to estimate probability distributions for all process CO_2-eq intensity of building materials. The probability distributions of embodied CO_2-eq intensities of building materials was derived by fitting a distribution using EASYFIT Statistical Application (MATHWAVE, 2009) to limited data of building materials embodied CO_2-eq intensities obtained from the database of Inventory of Carbon and Energy, v1.6a (Sustainable Energy Research Group, 2008). The distributions are ranked by Kolmogorov Smirnov goodness of fit from a set of 57 different distributions. Kolmogorov Smirnov was preferred to Anderson-Darling goodness of best fit because it is an exact test, that is, the chi-square goodness-of-fit test depends on an adequate sample size for the approximations to be valid. Moreover, Anderson-Darling test is only available for a few specific distributions

iv. Probability distributions are also derived for sub-sector direct CO_2-eq intensities of each of the five sub-sectors. Using disaggregated micro energy data used on site by construction firms from 2003 to 2006 (Central Statistics Office, 2005; 2006; 2007 and 2008a) the direct CO_2-eq intensity of each construction sub-sector was calculated. Probability distribution was then fitted on the disaggregated direct CO_2-eq intensities of each sub-sector using EASYFIT Statistical Application (MATHWAVE, 2009) and the statistical parameters of the distribution obtained.

v. The model is implemented using the Irish apartment buildings sector with 7 buildings used as case studies to demonstrate the approach. Only 7 case studies were used in the study because of difficulty in getting access to more data.

vi. The use of Monte Carlo techniques to derive probability and cumulative distributions for CO_2-eq intensities for apartment buildings are based on 70, 000 simulation results. Statistical parameters of each stochastic distribution (each building material and five construction sub-sectors) are used to derive random inputs for each of the 70, 000 simulations. Deterministic input variables such as expenditure and indirect sectoral I-O CO_2-eq intensities are kept constant.

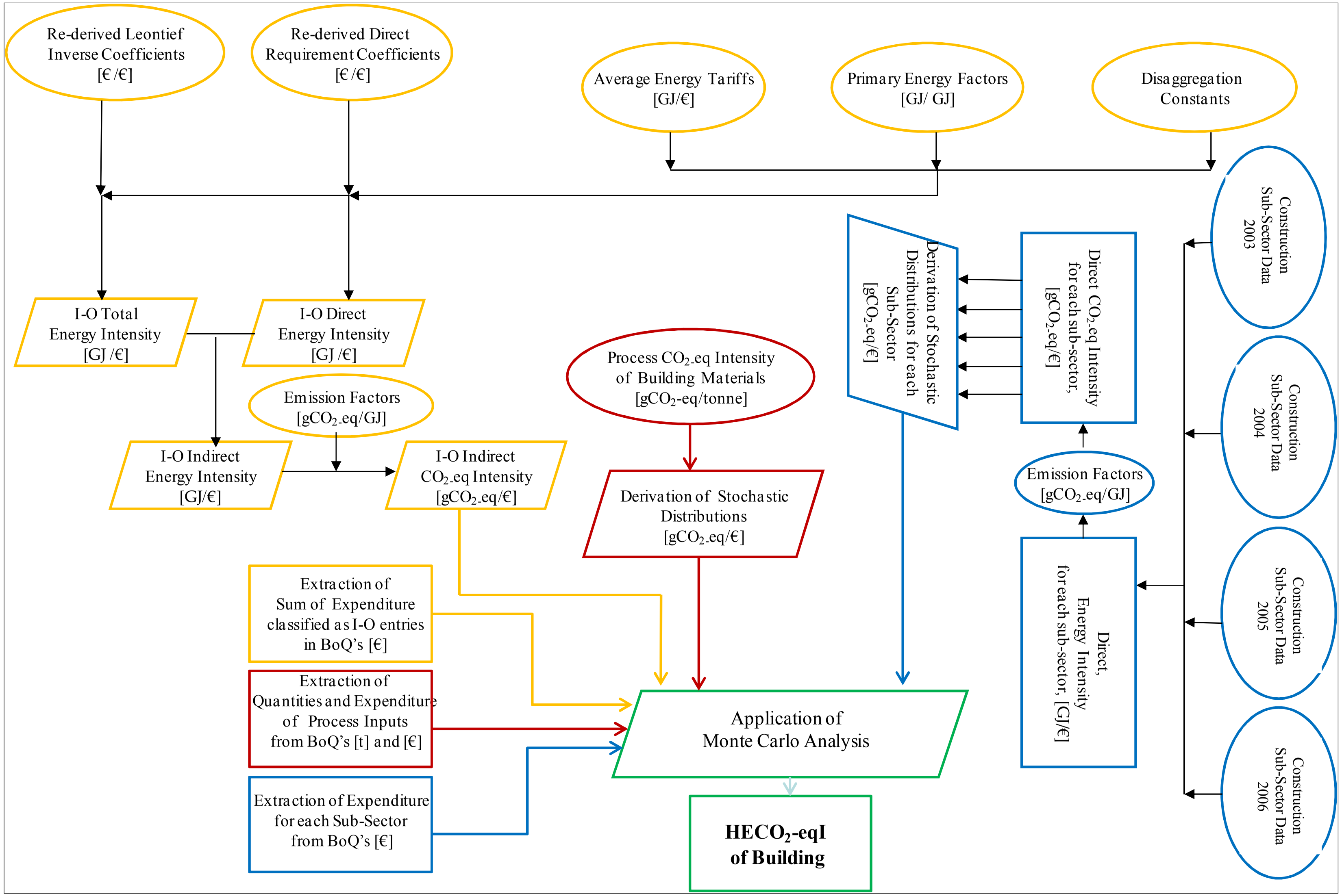
vii. An average $HECO_2$-eqI probability and cumulative distribution of the apartment building sector is obtained by combing the distributions of the seven case studies. Statistical parameters such as mean, median, percentiles and uncertainty are derived from the distribution

viii. Bayesian Inference is shown how it can be applied as an updating technique to update the derived prior distribution to a posterior distribution and in the analysis of uncertainty reduction

Figure 3.2 below is a flow chart description of the methodology used to combine different data sources of process and I-O methods to obtain $HECO_2$-eqI of a building and forming the basis for the stochastic analysis.

The functional unit adopted in the study is gCO_2-eq/€ and GJ/€. Treloar *et al.* (2001) for instance used this functional unit when he estimated that the total energy intensity of the residential building construction sector in Australia was 0.851 GJ/$100.

Figure 3.3 Flow Chart of Hybrid Embodied CO_2.eq Intensity ($HECO_2$-eqI) Stochastic Framework



3.2.1 Monte Carlo Application to Embodied CO_2-eq Analysis

The Monte Carlo technique uses statistical sampling to obtain a probabilistic approximation to the solution of a mathematical equation or model. It involves using probability to solve problems by iteratively evaluating a deterministic model using sets of random numbers as inputs. By using random inputs a deterministic model is turned into a stochastic model. A stochastic model is one that involves probability or randomness. The US EPA (1997) reported that probabilistic analysis techniques such as Monte Carlo analysis, given adequate supporting data and credible assumptions can be useful statistical tools for analyzing variability and uncertainty. This technique is applied to a novel model embodied CO_2-eq intensity relationship to characterize the distributions of $HECO_2$-eqI of apartment buildings in Ireland.

The general steps undertaken in a Monte Carlo technique are described below:

Step 1: Create a $HECO_2$-eqI mathematical relationship.

In this thesis, the Monte Carlo analysis is implemented using Equation 3.1.

Step 2: Generate a set of random inputs.

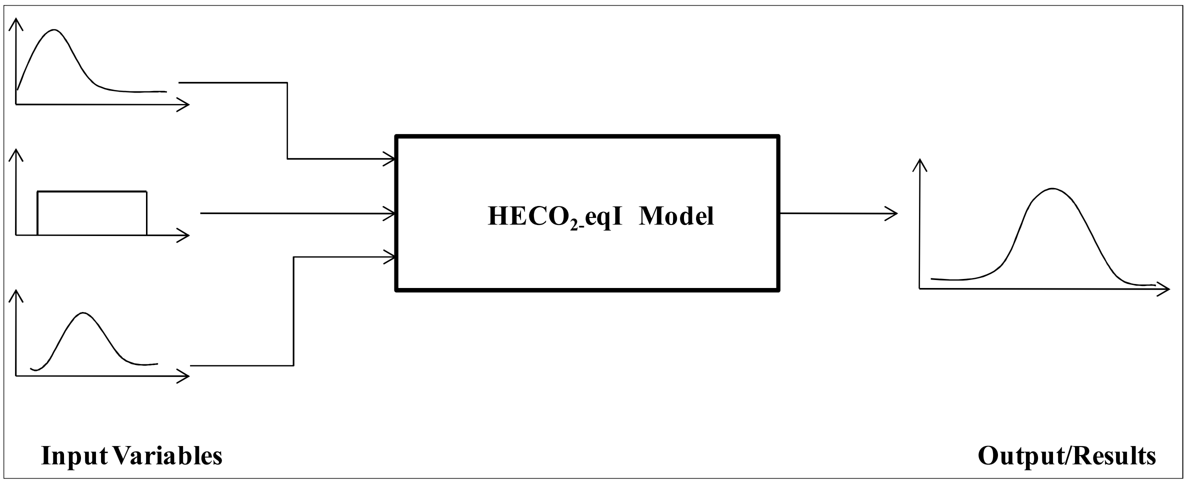
In the case of $HECO_2$-eqI, random inputs are generated for all process embodied CO_2-eq intensities of building materials and sub-sectoral direct CO_2-eq intensities for all five sub-sectors. This is achieved by setting up the Monte Carlo analysis on a spread sheet where by 10,000 rows represents 10,000 different simulations per case study. For each input variable in Equation 3.1, 10,000 random input variables are generated for the entire stochastic input variable (using the distributions presented in Chapter 5) together with 10, 000 average values for the deterministic variables (quantity of materials and expenditure).

Step 3**:** Evaluate the model and store the results.

The stochastic hybrid relationship presented in Equation 3.1 is solved 10, 000 times generating 10, 000 results per each case study.

Step 4: The results are analysed using probability distributions, histograms, cumulative distributions, summary statistics, etc.

Figure 3.4: Steps Undertaken in a Monte Carlo Analysis



The mathematical expression of HECO$_2$-eqI (with units: gCO$_2$-eq/€) is given by the following hybrid relationship in Equation 3.1:

$$\mathrm{HECO}_{2\text{-}}\mathrm{eqI} = \frac{\left[\sum_{x=1}^{n} M_x e_x\right] + \left[i_i \sum_{j=1}^{5} S_j + \sum_{j=1}^{5} i_{dj} S_j\right]}{\sum_{j=1}^{5} S_j + C_p}$$

M_x = Mass of building material x [tonnes, t]

n = Number of building materials for which process emissions intensities and quantities exist

e_x = process CO$_2$-eq intensity of building material x [gCO$_2$-eq/t]

i_i = Input-output sectoral indirect CO_2-eq intensity of construction [gCO_2-eq/€]

i_{dj}= Direct sub-sectoral CO_2-eq intensity of each construction subsector j [gCO_2-eq/€]

j = Number of construction sub-sectors

S_j = Expenditure classified by construction sub-sector, j on activities associated with the construction of the building [€]

C_p = Total expenditure of building materials associated with process CO_2-eq intensity inventory [€]

Equation 3.1 expresses the total hybrid embodied CO_2-eq intensity of the building as the sum of the process embodied CO_2-eq of the building materials [gCO_2-eq], the I-O sectoral indirect embodied CO_2-eq of the building [gCO_2-eq] and the respective sub-sectoral direct embodied CO2-eq [gCO_2-eq]. These embodied emissions are divided by the total cost of the building [$C_p + \sum_{j=1}^{5} S_j$] at basic prices [€] to give the total hybrid embodied CO_2-eq intensity of the building.

It is assumed that waste factors of building materials will have negligible impact on the quantities of building materials used. That is, the ratio of delivered materials to site to used materials is assumed to be 1.

To avoid double counting of inputs into the model for which process data has been collected (that is, for embodied CO_2-eq intensities of building materials), the following steps were undertaken:

- The building materials were extracted from the bill of quantities together with its associated total expenditure, C_p noted
- The rest of the entries in the bill of quantities represented I-O components with direct requirement components and indirect requirement components has associated expenditure given by: $\sum_{j=1}^{5} S_j$.
- The indirect emissions component of the building which potentially can contain the indirect emissions of the building materials is calculated as $\left[i_i \sum_{j=1}^{5} S_j \right]$ minus C_p ; the expenditure component of the building materials.

3.3 Methodology for Assessing Proposed Building and Construction Sector Emissions Policies

The formulation of evidence-based policies requires quantitative information; as such the stochastic application to $HECO_2$-eqI of apartment building in Ireland is used as quantitative basis for the assessment of proposed emissions policies. Two building and construction emissions policies are proposed based on their effectiveness in reducing the embodied CO_2-eq emissions in buildings and in the construction sector. The stochastic $HECO_2$-eqI distributions framework is used to assess the effectiveness of these policy options.

The effectiveness of Policy Option 1, a mandatory certification and labelling instrument was assessed by comparing the average $HECO_2$-eqI of apartment building in Ireland to a truncated distribution. The truncated distribution is derived by placing a cap on the stochastic process embodied CO_{2}-eq intensities of building materials up to the 80th percentile of the stochastic distribution. Based on assumptions, estimations of possible saving in emissions in Ireland and in EU-27 are made. Policy Option 2; a Support, Informational and Voluntary Action policy is assessed by undertaking normalized comparisons of buildings using HECO_{2}-eqI cumulative distributions. Furthermore, the savings in embodied CO_{2}-eq using Policy Option 2 is demonstrated using probability intensity distribution rating scheme.

3.4 Case Studies

Table 3.1: General Description of Case Studies
(Refer to Appendices VII to XIII for detailed description)

Apartments	Description of Apartment Buildings
Apartment 1	Concrete piled foundation, reinforced concrete frame with infill 215mm block-work; 320mm thick reinforced concrete slab with 400mm x 600mm reinforced concrete columns on 9m x 9m grids. External finishes included brickwork and render, double-glazed timber-framed windows, thermafloor insulation and concrete roof tiles. Internal finishes included timber stud partitions, plasterwork and painting.
Apartment 2	Reinforced concrete frame with minor structural steel to roof; 300mmthick reinforced concrete slab with 400mm x 400mm reinforced concrete columns on 8m x 8m grids. Thermafloor insulation and external finishes include plaster work with gloss paint to wood work. Roof work consists of mastic asphalt roofing with rigid sheet covering and decking. Mechanical installations made up of waste, water, gas, heating, HVAC, and lift
Apartment 3	Reinforced concrete substructure, block work external walls 440 x 215 x 100, concrete work in concrete frame structure, woodwork and precast pre-stressed concrete work for stairs, structural steel work fabricated members, internal walls partitioned with softwood and thermafloor insulation.
Apartment 4	Reinforced concrete substructure with reinforced concrete in-situ concrete frame, fabricated members steel work, concrete work stairs 1.2m wide, block work internal walls 100 x 215 x 440, in-situ concrete floors and slabs exceeding 150mm reinforced and thermafloor insulation.
Apartment 5	Structural steel work with fabricated members, brickwork and block work internal walls with concrete blocks 100 x 215 x 440. In-situ concrete floors slabs exceeding 150mm thick and precast concrete 200mm thick with span >5.00m and <7.00m. Thermafloor insulation and structural steel work roof 254 x 146 x 37kg/m Universal Beam.
Apartment 6	Reinforced concrete substructure, brickwork and concrete work size 440 x 215 x 100, Floor insulation laid to underside of floor, in-situ concrete floor exceeding 150mm thick. Concrete walls consist of reinforced in-situ concrete with thickness not exceeding 0.20m. Concrete screed floor 75mm thick with fabric reinforcement.
Apartment 7	Reinforced concrete substructure, brickwork and concrete work size 440 x 215 x 100; Brick and block work external walls, coping to parapet 560 x 150. Precast Concrete Lintels, 100 x 65mm, Insulation board 100mm thick, Structural steel work 50 x 90 x 10kg/m stainless steel. Roof with insulation

CHAPTER 4:

Construction Sector and Sub-Sectors Embodied Energy and CO_2-eq Intensity Analysis

4.0 Assessment of the Total Embodied Energy and CO_2-eq Intensity of Irish Construction and Construction Sub-Sectors

This section presents the systematic evaluation of the total embodied energy and CO_2-eq intensity of Irish construction and construction sub-sectors. These were achieved by optimising data relevant to Ireland and advancing current methodologies by identify improvements in input-output aggregation (energy supply and construction sectors) and system boundary completeness. The total embodied CO_2-eq intensity of Irish construction and construction sub-sectors was evaluated as the sum of the sub-sectoral direct embodied CO_2-eq intensity and I-O sectoral embodied indirect CO_2-eq intensity. Also included in this section are methodological advances and analysis of construction sub-sector results.

4.1 Sub-Sectoral Direct Embodied Energy and CO_2-eq Intensities

Direct embodied energy of construction is the energy used directly on the construction site and goes into putting up a building (for example: for excavation, fit-out and services) and consequently results in the emission of direct CO_2-eq into the atmosphere. The sub-sectoral direct embodied energy and CO_2-eq intensity of construction is determined at a sub-sector level rather than at the aggregated sectoral level in order to exploit data collected on energy purchases in the Census of Construction, thus improving on the aggregated construction sector data contained in the national I-O tables. The sub-sectoral direct energy intensities are calculated from construction company data collected by the Irish Central Statistics Office which categorizes electricity and fuel expenditure according to five construction sub-sectors. It is assumed that fuel used was diesel since vast majority of plant and construction machinery operates on diesel fuel (Central Statistics Office, 2007). To ensure consistency with other data used in the hybrid assessment, all prices are converted to year 2005 using construction and energy price indices. 2005 is taken as the baseline year because it is the most recent year in which the Central Statistics Office has published Supply and Use and Input-Output Tables for Ireland.

A representative sample of Irish building and construction firms was surveyed in a yearly census from 2003 to 2006 and the electricity and fuel purchases of each were recorded. 682 firms were surveyed in 2003, 628 in 2004, 728 in 2005 and 1291 in 2006. The Central Statistics Office (2008a) reported that the significant increase in the number of firms covered in 2006 census compared to earlier years is due to recent improvements in increased coverage to the CSO Central Business register of firms and increased access to administrative data sources that support the register.

Energy expenditure is divided among five construction sub-sectors defined by 'The General Industrial Classification of Economic Activities within the European Communities (NACE rev. 1)'. Construction sub-sectors 1-5 are hereafter referred to as 'Ground Works', 'Structural Work', 'Services', 'Finishes' and 'Plant Operation' respectively. The sub-sectors are defined in detailed below:

Ground Works: Site preparation, demolition of buildings, earth moving, ground work, drilling and boring, etc (NACE 45.1)

Structural Work: Building of complete constructions or part thereof; civil and structural construction works, etc (NACE 45.2)

Services: Building installation, installation of electrical wiring and fittings, insulation, plumbing and other installations, etc (NACE 45.3)

Finishes: Building completion, joinery installation, plastering, floor and wall, covering, painting, glazing and general fit-out, etc (NACE 45.4)

Plant Operation: Construction plant and equipments, etc (NACE 45.5)

For each construction sub-sector, the equivalent primary energy in gigajoules used was calculated using energy expenditure [€] (Central Statistics Office, 2005; 2006; 2007 and 2008a), average energy tariffs [GJ/€]-this is actually the inverse of energy tariffs usually expressed in terms of [€/GJ]-(Sustainable Energy Authority of Ireland, 2009) and primary energy factors [GJ/GJ] (Sustainable Energy Authority of Ireland, 2007). The energy in GJ was then derived per Euro [€] output of each sub-sector.

Mathematically, the sub-sectoral direct embodied energy intensities i_{dj} calculated for each of the years (2003-2006) and for each construction sub-sector are given by Equation 4.1 below:

Equation 4.1:

$$\text{Sub} - \text{Sectoral Direct Embodied Energy Intensities}, i_{dj} = \frac{Q_{(e,d)j} \times T_{(e,d)j} \times P_{(e,d)}}{E_j}$$

Similarly, the direct sub-sectoral embodied CO_2-eq intensities calculated for each of the years (2003-2006) and for each construction sub-sector are given by Equation 4.2:

Equation 4.2:

$$\text{Sub} - \text{Sectoral Direct Embodied } CO_{2-eq} \text{ Intensities} = \frac{Q_{(e,d)j} \times T_{(e,d)j} \times P_{(e,d)} \times I_{(e,d)}}{E_j}$$

$Q =$ Monetary value of electricity or diesel consumed [€]

$T =$ Average energy tariff [GJ/€]

$P =$ Primary Energy Factor

$E =$ Output of each sub − sector [€]

$I =$ Emission factors for electricity and diesel [gCO_{2-eq}/GJ]

$j =$ Construction sub − sector

$e =$ Electricity

$d =$ Diesel

The average sub-sectoral direct embodied energy intensities (i_{Dj}) for each sub-sector is then calculated as the weighted average of the sub-sectoral direct embodied energy intensities (i_{dj}) from 2003-2006. The averages are weighted to the output of each sub-sector from 2003-2006. This is represented mathematically in Equation 4.3 as:

$$\text{(Weighted)average sub} - \text{sector direct embodied energy int. } i_{Dj} = \frac{\left(\sum_{\substack{k=j \\ y=2003}}^{y=2006} i_{dky} \times E_{ky} \right)}{\sum_{\substack{k=j \\ y=2003}}^{y=2006} E_{ky}}$$

The direct embodied energy intensity of Irish construction i_{DT} is calculated as the averages of i_{Dj} and is given by Equation 4.4:

$$\text{Direct Sub-Sectoral Embodied Energy Intensity, } \mathrm{i}_{\mathrm{DT}} = \frac{\left(\sum_{j=1}^{5} i_{Dj} \times E_{wj}\right)}{\sum_{j=1}^{5} E_{wj}}$$

$y =$ Year 2003 to Year 2006

$\mathrm{E_w}$ = Weighted average of Sub-Sector Output from 2003 to 2005

4.1.1 Energy and Construction Price Indices

To correct for the different years in the ages of the data used in the study, consumer price indices were applied to normalize each data set to the baseline year of 2005. A consumer price index measures a price change for a constant market basket of goods and services from one period to the next within the same country. The energy price index and construction sub-sector output price index are calculated from construction price index and energy price index published by the Central Statistics Office (2009c).

Table 4.1: Energy and Construction Sector Price Indices (CSO, 2009c)

Year	**Construction sub-sector output price index**	**Energy price index**
2003	1.151	1.221
2004	1.104	1.126
2005	1.000	1.000
2006	0.861	0.924

4.1.2 Primary Energy Factors

Primary energy factor is primary energy (resource energy) divided by delivered energy. Primary energy is that required to supply one unit of delivered energy of the same type taking account of the energy required for extraction, processing, storage, transportation, generation, transformation, transmission, distribution and any other operational requirement for delivery to where the delivered energy will be used (CEN Technical Committee, 2004). The difference in the quantity of primary energy used as fuel and final delivered energy is therefore due to own use and efficiency losses. Primary energy factors for each of the Irish energy supply sectors were calculated for the year 2005 from the 1990-2005 Irish energy statistics database (Sustainable Energy Authority of Ireland, 2007). Primary energy factors are used to convert energy intensities derived from the input-output tables and construction sub-sector data into primary energy terms in order to account for the original resource energy used. For electricity, the primary energy factor is also affected by plant generation efficiency which is assumed to be 40.6% in this study (EUROPA, 2009)

.

Table 4.2: Primary Energy Factors (Sustainable Energy Authority of Ireland, 2006)

	Final Consumption [KTOE]	**Losses [KTOE]**	**Primary Energy Req. [KTOE]**	**Primary Energy Factor**
Peat	301	5	306	1.02
Crude Oil	6525	332	6857	1.05
Coal	401	0	401	1.00
Petroleum	7070	92	7162	1.01
Natural Gas	1586	28	1616	1.02
Electricity	1737	285 + η=40.6%	4980	2.86
Renewable	141	0	141	1.00

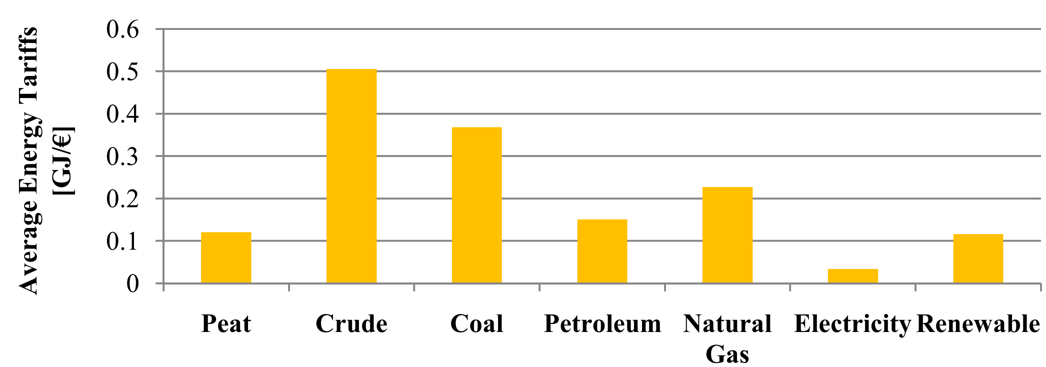
4.1.3 Energy Tariffs and Prices

According to Miller *et al.,* (1985) in order to relate economic data to physical quantities, price assumptions are required. Economic data on energy used are converted to physical quantities using national energy tariffs. The average national energy tariff describes the average price paid for energy supplied by a given energy supply sector. The prices at which energy supplies are sold and bought in Ireland are not used because of negotiated energy tariffs which may not be representative of the national average. The set of energy tariffs for the Irish energy supply sectors are calculated from energy balance of Ireland (Sustainable Energy Authority of Ireland, 2009) as the ratio of the total energy usage across all intermediate sectors of the economy [GJ] and the total economic demand for these energy supplies across the intermediate sectors of the economy [€]. The energy prices are corrected to the 2005 baseline year using energy price index published the Central Statistics Office (2009c).

Table 4.3: Average Energy Tariffs derived from the Irish Energy Balance (Sustainable Energy Authority Ireland, 2009)

	Units	Peat	Crude	Coal	Petroleum	Natural Gas	Electricity	Renewable
Total Usage Supplied to each Sector of Economy	KTOE	605	3,250	1,566	6,355	2,463	1,278	211
Total Usage supplied to each Sector of Economy	GJ	25,330,140	136,071,000	655,652,288	266,071,140	103,120,884	53,507,304	8,834,148
Total Demand of Energy Supplies	€m	209.3	269.2	178.1	1765.8	454.3	1586.2	76.3
Average Energy Tariff, T_e	GJ/€	0.1210	0.5055	0.3681	0.1507	0.2270	0.0337	0.1158

Figure 4.1: 2005 Average Energy Tariffs of the Energy Supply Sectors in Ireland



Year: 2003
Firms Surveyed: 682
Price index to correct Energy Tariff to 2005 baseline: 1.221
Price index to correct sub-sector output to 2005 baseline: 1.151

Table 4.4: Summary of 2003 construction sub-sector analysis of energy use data of Irish construction firms

	Units	Sub-Sector 1 (NACE 45.1) Ground Works	Sub-Sector 2 (NACE 45.2) Structural Work	Sub-Sector 3 (NACE 45.3) Services	Sub-Sector 4 (NACE 45.4) Finishes	Sub-Sector 5 (NACE 45.5) Plants Operations
Electricity Expenditure	€000	185	12,238	1,020	277	166
Fuel Expenditure	€000	6,654	36,479	3,518	1,691	4,113
Electricity Expenditure at 2005 Price	€000	225.885	14,943	1,245	338.217	202.686
Fuel Expenditure at 2005 Price	€000	8,125	44,541	4,295	2,065	5,022
Equivalent Electricity Used	GJ	7,612	503,566	41,971	11,398	6,831
Equivalent Fuel Used	GJ	429,788	2,356,211	227,231	109,223	265,662
Primary Energy Electricity Used	GJ	21,771	1,440,197	120,036	32,598	19,535
Primary Energy Fuel Used	GJ	434,086	2,379,774	229,503	110,315	268,319
Total Equivalent Primary Energy	GJ	455,857	3,819,971	349,539	142,913	287,854
Sub-Sector Output	€1000	197,292	5,572,949	1,215,417	208,831	69,054
Sub-Sec Output at 2005 Price	€1000	227,083	6,414,464	1,398,945	240,364	79,481
Energy Intensity	GJ/€	0.002007	0.000596	0.000250	0.000595	0.003622

Year: 2004
Firms Surveyed: 628
Price index to correct Energy Tariff to 2005 baseline: 1.126
Price index to correct sub-sector output to 2005 baseline: 1.104

Table 4.5: Summary of 2004 construction sub-sector analysis of energy use data of Irish construction firms

	Units	Sub-Sector 1 (NACE 45.1) Ground Works	Sub-Sector 2 (NACE 45.2) Structural Work	Sub-Sector 3 (NACE 45.3) Services	Sub-Sector 4 (NACE 45.4) Finishes	Sub-Sector 5 (NACE 45.5) Plants Operations
Electricity Expenditure	€000	148	15,679	1,298	210	138
Fuel Expenditure	€000	6,462	53,186	7,498	1,944	5,952
Electricity Expenditure at 2005 Price	€000	167	17,655	1,462	236	155
Fuel Expenditure at 2005 Price	€000	7,276	59,887	8,443	2,189	6,702
Equivalent Electricity Used	GJ	5,616	594,958	49,254	7,969	5,237
Equivalent Fuel Used	GJ	384,912	3,168,045	446,621	115,795	354,533
Electricity Used in Primary Energy Terms	GJ	16,062	1,701,581	140,867	22,790	14,977
Fuel Used in Primary Energy Terms	GJ	388,761	3,199,726	451,088	116,953	358,079
Total Equivalent Primary Energy	GJ	404,823	4,901,307	591,955	139,744	373,055
Sub-Sector Output	€000	190,805	6,973,740	1,268,295	187,039	84,106
Sub-Sector Output at 2005 Price	€000	210,649	7,699,009	1,400,198	206,491	92,853
Energy Intensity	GJ/€	0.001922	0.000637	0.000423	0.000677	0.004018

Year: 2005
Firms Surveyed: 728
Price index to correct Energy Tariff to 2005 baseline: 1.341

Table 4.6: Summary of 2005 construction sub-sector analysis of energy use data of Irish construction firms

	Units	Sub-Sector 1 (NACE 45.1) Ground Works	Sub-Sector 2 (NACE 45.2) Structural Work	Sub-Sector 3 (NACE 45.3) Services	Sub-Sector 4 (NACE 45.4) Finishes	Sub-Sector 5 (NACE 45.5) Plants Operations
Electricity Expenditure	€000	509	23,753	1,438	220	185
Fuel Expenditure	€000	9,922	56,552	6,660	861	6,775
Electricity Expenditure at 2005 Price	€000	509	23,753	1,438	220	185
Fuel Expenditure at 2005 Price	€000	9,922	56,552	6,660	861	6,775
Equivalent Electricity Used	GJ	17,153	800,476	48,461	7,414	6,235
Equivalent Fuel Used	GJ	524,874	2,991,601	352,314	45,547	358,398
Electricity Used in Primary Energy Terms	GJ	49,058	2,289,362	138,597	21,204	17,831
Fuel Used in Primary Energy Terms	GJ	530,123	3,021,517	355,837	46,002	361,981
Total Equivalent Primary Energy	GJ	579,181	5,310,878	494,434	67,206	379,812
Sub-Sector Output	€1000	367,971	7,759,276	1,484,952	161,121	92,821
Energy Intensity	GJ/€	0.001574	0.000684	0.000333	0.000417	0.004092

Year: 2006
Firms Surveyed: 1291
Price index to correct Energy Tariff to 2005 baseline: 0.924
Price index to correct sub-sector output to 2005 baseline: 0.861

Table 4.7: Summary of 2006 construction sub-sector analysis of energy use data of Irish construction firms

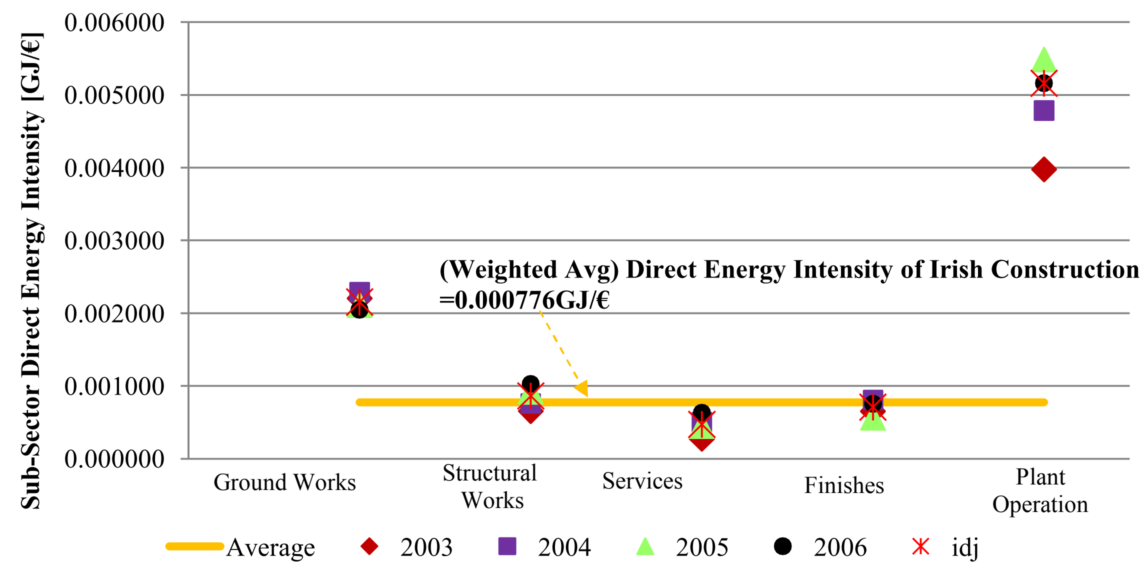
	Units	Sub-Sector 1 (NACE 45.1) Ground Works	Sub-Sector 2 (NACE 45.2) Structural Work	Sub-Sector 3 (NACE 45.3) Services	Sub-Sector 4 (NACE 45.4) Finishes	Sub-Sector 5 (NACE 45.5) Plants Operations
Electricity Expenditure	€000	323	28,212	1,828	545	271
Fuel Expenditure	€000	6,297	95,774	11,608	3,112	11,108
Electricity Expenditure at 2005 Price	€000	433	37,832	2,451	731	363
Fuel Expenditure at 2005 Price	€000	8,444	128,433	15,566	4,173	14,896
Equivalent Electricity Used	GJ	14,597	1,274,948	82,610	24,629	12,247
Equivalent Fuel Used	GJ	446,702	6,794,102	823,459	220,762	787,989
Electricity Used in Primary Energy Terms	GJ	41,747	3,646,352	236,266	70,440	35,026
Fuel Used in Primary Energy	GJ	451,169	6,862,043	831,693	222,969	795,869
Total Equivalent Primary Energy	GJ	492,916	10,508,395	1,067,959	293,410	830,895
Sub-Sector Output	€1000	279,681	11,889,079	1,970,660	450,903	164,870
Sub-Sector Output at 05 Price	€000	240,805	10,236,497	1,696,738	388,227	141,953
Energy Intensity	GJ/€	0.002047	0.001027	0.000629	0.000756	0.005853

Table 4.8: Summary of Sub-Sector Direct Embodied Energy Intensities Results

	Sub-Sector 1 (NACE 45.1) Ground Works		**Sub-Sector 2 (NACE 45.2) Structural Work**		**Sub-Sector 3 (NACE 45.3) Services**		**Sub-Sector 4 (NACE 45.4) Finishes**		Sub-Sector 5 (NACE 45.5) Plants Operations	
	i_{d1} **[GJ/€]**	S_1 **[€]**	i_{d2} **[GJ/€]**	S_2 **[€]**	i_{d3} **[GJ/€]**	S_3 **[€]**	i_{d4} **[GJ/€]**	S_4 **[€]**	i_{d5} **[GJ/€]**	S_5 **[€]**
2003	0.002007	227,083	0.000596	6,414,464	0.000250	1,398,945	0.000595	240,364	0.003622	79,481
2004	0.001922	210,649	0.000637	7,699,009	0.000423	1,400,198	0.000677	206,491	0.004018	92,853
2005	0.001574	367,971	0.000684	7,759,276	0.000333	1,484,952	0.000417	161,121	0.004092	92,821
2006	0.002047	240,805	0.001027	10,236,497	0.000629	1,696,738	0.000756	388,227	0.005853	141,953
Weighted Avg. i_{Dj}	**0.001847**	**255,991**	**0.000764**	**8,338,173**	**0.000419**	**1,531,424**	**0.000646**	**263,183**	**0.004597**	**106,435**
Direct Energy Int; i_{DT}	**0.000776**	**[GJ/€]**								

The derived results of the direct embodied energy intensities of each construction sub-sector are presented in Figure 4.2 below.

Fig. 4.2 Variations in Sub-Sector Direct Energy Intensities from 2003-2006



It can be observed that from 2003 to 2006, that the sub-sector direct energy intensities remained relatively constant between sub-sectors 1 (Ground Works) to 4 (Finishes). In sub-sector 5 (Plant Operations) between 2003 and 2005 the sub-sector direct energy intensities increased gradually but dropped slightly in 2006. This can be attributed to increase construction activity and consequently increase use of plant machinery over that period.

A sub-sectoral analysis of the Irish construction sector showed that the direct sub-sector energy intensity of each of the sub-sector ranged from 0.00047GJ/€ (Finishes) to 0.00516 GJ/€ (Plants Operations). It can be seen from Table 4.8 above that the sub-sectoral direct embodied energy intensity of Irish construction is dominated by sub-sector 2 (Structural

Works) because of the level of construction output in that sector. It is estimated that the direct energy intensity of Irish construction is 0.000776GJ/€.

4.2 Sub-Sectoral Direct Embodied CO_2-eq Intensity

The sub-sectoral direct energy intensities for the construction sub-sector were converted to sub-sectoral direct CO_2-eq intensities using Irish emission factors and Irish electricity fuel mix ratios. This is done for each year between 2003 and 2006 and the average determined by weighting it to the output of each sub-sector a similar to Equation 4.3 and 4.4.

The amount of electricity used on site was disaggregated into the source of fuel used in the generation of the electricity using the electricity fuel mix ratios in Ireland (Commission for Energy Regulation, 2006) and then converted to primary energy terms using Irish primary energy factors (Sustainable Energy Authority of Ireland, 2007). The appropriate emission factors (Sustainable Energy Authority of Ireland, 2003) are then applied for each fuel source. Emission factors were also applied to diesel used on site (National Lab for Sustainable Energy, 2007). For each sub-sector and for each year between 2003 and 2006 the GHG emissions due to electricity and diesel usage on site was determined and converted to the equivalent embodied CO_2-eq intensity. From Figure 4.3 below, it can be observed that the variation in the sub-sector direct embodied CO_2-eq intensities follows similar trend as the sub-sector direct embodied energy intensities in Figure 4.2.

4.2.1 Embodied CO_2 Equivalence (CO_2-eq)

Equivalent CO_2 (CO_2-eq) is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas (GHG). Energy-derived GHGs such as CO_2, N_2O and CH_4 have different impacts on global warming and can be weighted according to their global warming potential (GWP). This is the ratio of the warming caused by a substance to the warming caused by a similar mass of carbon dioxide and is termed CO_2-equivalent or CO_2-eq (IPCC, 2006). The GWP of the energy-related GHGs regulated under the Kyoto Protocol over a 100 year timeframe which are relevant to this study are: CO_2-1; N_2O-310; and CH_4-21. The GWPs for each of the above emissions were summed to give total embodied CO_2-eq intensities for the construction sector.

4.2.2 Irish Emission Factors

The emission factors for electricity generation are published by Sustainable Energy Authority of Ireland (2003). Table 4.9 below are derived factors presented in terms of g/GJ of the particular energy-derived GHG. Emission factors for diesel were obtained from the National Lab for Sustainable Energy (2007)

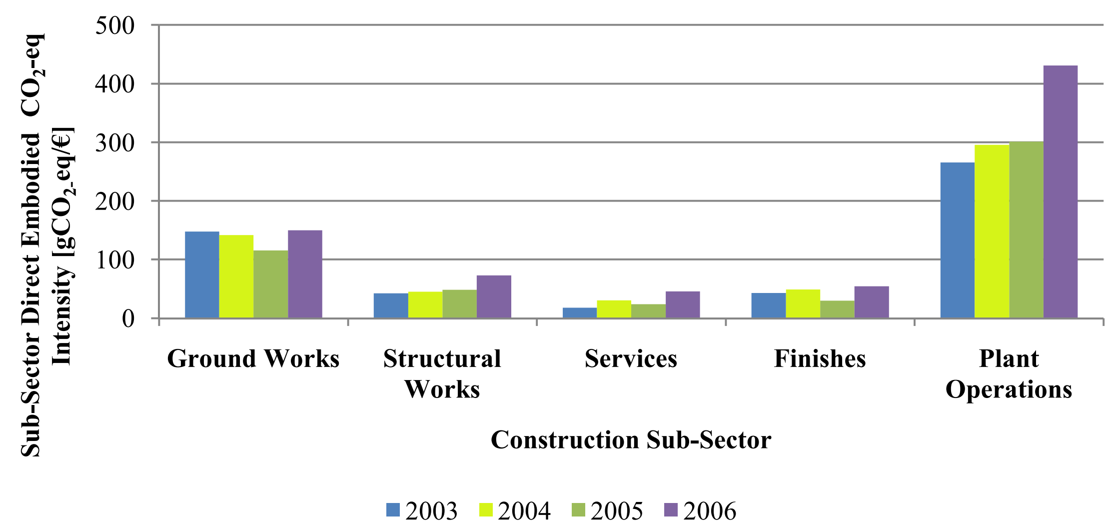
Table 4.9: Electricity and Diesel Emission Factors

Fuel	Gen. Eff.(η)	Generation Mix	N_2O [g/GJ]	CH_4 [g/GJ]	CO_2 [g/GJ]
Coal	0.37	0.24	2.11	1.50	88,418
Oil	0.38	0.12	2.00	3.00	78,500
Peat	0.385	0.08	1.83	1.56	105,949
Natural Gas	0.414	0.47	0.69	2.50	55,196
Renewable Energy	1	0.09	0.00	0.00	0.00
Diesel	-	-	1.77	3.95	73,300

Derived from Sustainable Energy Authority of Ireland (2003)

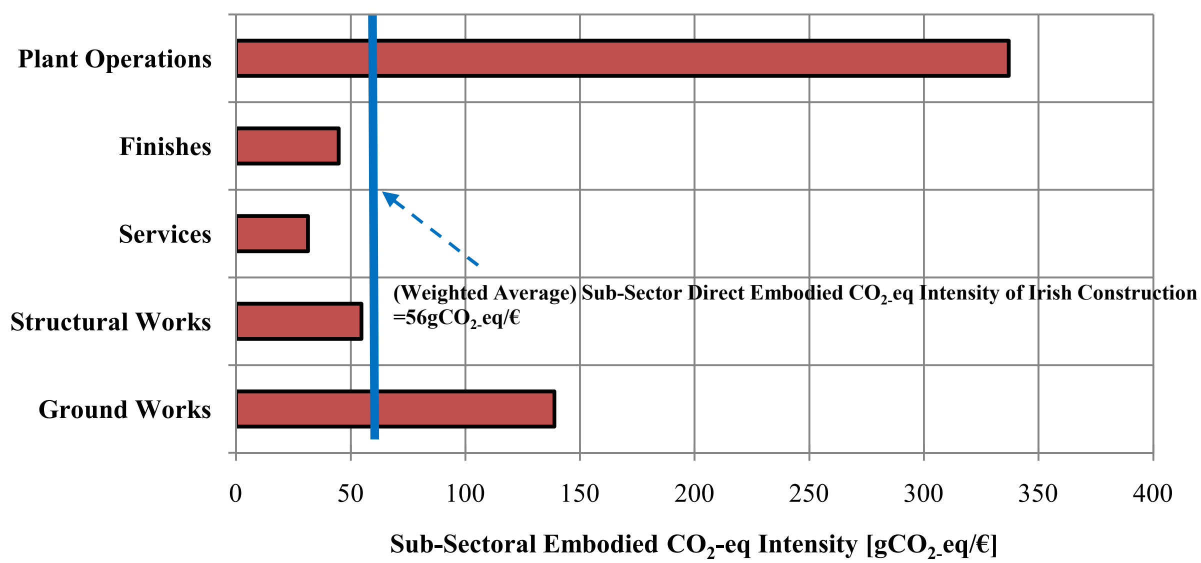
An embodied CO_2-eq intensity of 56gCO_2-eq/€ was estimated as the sub-sector direct embodied CO_2-eq intensity of Irish construction. Refer to Figure 4.4. The average embodied CO_2-eq intensity of each sub-sector was derived after weighting it to the output of each sub-sector over the 4 year analysis period. The analysis was undertaken from 2003-2006 (Refer to Figure 4.3) in order to obtain a large sample size and smooth any variability in construction activities that might have occurred over the years. The GHG contribution to the sub-sector direct embodied CO_2-eq intensity was dominated by CO_2 contributing more than 99% of the CO_2-eq over each of the four years analysed.

Figure 4.3: Variation in Direct CO_2-eq Intensity in each Construction Sub-Sector from 2003-2006



The value of 56gCO_2-eq/€ was dominated by the sub-sector 2 (Structural Works) which had an embodied CO_2-eq intensity of 55gCO_2-eq/€ because of the level of construction activities in that sub-sector. Sub-sector 5 (Plant Operations) recorded the highest embodied CO_2-eq intensity for a sub-sector in each year averaging 337gCO_2-eq/€ (See Figure 4.4 below). Direct embodied emissions associated with capital equipments are captured in sub-sectoral direct embodied intensity of sub-sector 5 (Plant Operations) while indirect embodied emissions associated with capital equipments are captured in the I-O indirect embodied CO_2-eq intensity. Crawford (20008) showed that energy and emissions associated with capital equipments can represent 20% of the total embodied energy and emissions.

Figure 4.4: Weighted Sub-Sectoral Direct Embodied CO_2-eq Intensities



The low level of construction output in Sub-Sector 5 (Plant Operations) means that it makes a relatively small contribution to the direct sub-sectoral-based embodied CO_2-eq intensity of the whole construction sector. Ground Works, Services and Finishes had sub-sectoral embodied CO_2-eq intensities of 139gCO_2-eq/€, 31gCO_2-eq/€ and 4gCO_2-eq/€.

By assuming that the output of each sub-sector corresponds to the level of construction activity in that sub-sector, Sub-sector 2 (Structural Works) dominates construction activities with an estimated 79% of all construction activities and the least being Sub-Sector

5 (Plant Operations) with 1% of construction activities. The contributions in the level of Irish construction activities from Sub-Sector 1 to Sub-Sector 5 are in the ratio 2%, 79%, 15%, 3% and 1% respectively. In the EU-27, the ranking of construction activity in the sub-sectors are similar to the Irish construction sector. EUROSTAT (2010) reported that, the level of construction output in EU-27 by each sub-sector (1-5) in terms of value added are respectively Sub-Sector 1 (Ground Works)-3.4%; Sub-Sector 2 (Structural Works)-58%, Sub-Sector 3 (Services)-22.2%, Sub-Sector 4 (Finishes)-15.4% and Sub-Sector 5 (Plant Operation)-0.9%. The relative level of activities and the embodied CO_{2}-eq intensity of each sub-sector show where the emphasis should be placed when formulating strategies to tackle energy usage and CO_{2}-eq emissions in the construction sector.

4.3 Input-Output Sectoral Indirect Embodied Energy Intensity

Indirect embodied energy is not directly related to on-site construction but rather it occurs upstream of on-site construction and includes the construction procurement supply chain (for example: energy used to manufacture building materials, excavation of raw aggregate, design team activities). I-O embodied energy intensities were estimated using data from the Irish national I-O tables. Recent Irish input-output tables published by the Central Statistics Office include the 1998, 2000 and 2005 Supply and Use and Input-Output Tables. The 2005 I-O tables are used in the calculations in this study, hence 2005 is chosen as the base line year.

The Irish economy in the 2005 I-O tables is divided into a 53 by 53 different economic sectors or NACES consisting of three aggregated energy supply sectors, namely:

- Coal, Peat, Crude and Metal Ore extraction: NACE 10-13
- Petroleum and Other Manufacturing Products: NACE 23 and 36
- Electricity and Gas: NACE 40

The main advantage of input-output analysis in energy and environmental research studies relates to the extended system boundary that it offers over process-based approaches (Born *et al.*, 1996 and Crawford, 2008). I-O analysis overcomes the limitation of system boundary incompleteness of process analysis through the use of I-O Leontief Inverse Matrix. The Leontief Inverse Matrix employs a power series approximation to account for all upstream economic inputs to a product sector; consequently, all energy expenditure is also accounted for. However, the Irish Leontief Inverse Matrix was derived by measuring domestic product flows only; the energy inputs into imported products have been omitted. In order to extend the I-O system boundary to include imported goods and services, the matrices of direct requirement coefficient and Leontief inverse matrices are re-derived by employing the methodology set out in the Eurostat European System of Accounts I-O Manual (EUROSTAT, 2002). The re-derived matrices consisting of two regions: Irish domestic and Irish imports are presented in Appendices I-VI.

The addition of energy inputs into imported construction sector goods and services is important in an open economy such as Ireland's (SCCI, 2006). This is because it provides greater information for decision making by designers and policy makers by considering total global indirect upstream impacts given that national energy and emissions policies emanate from EU directives.

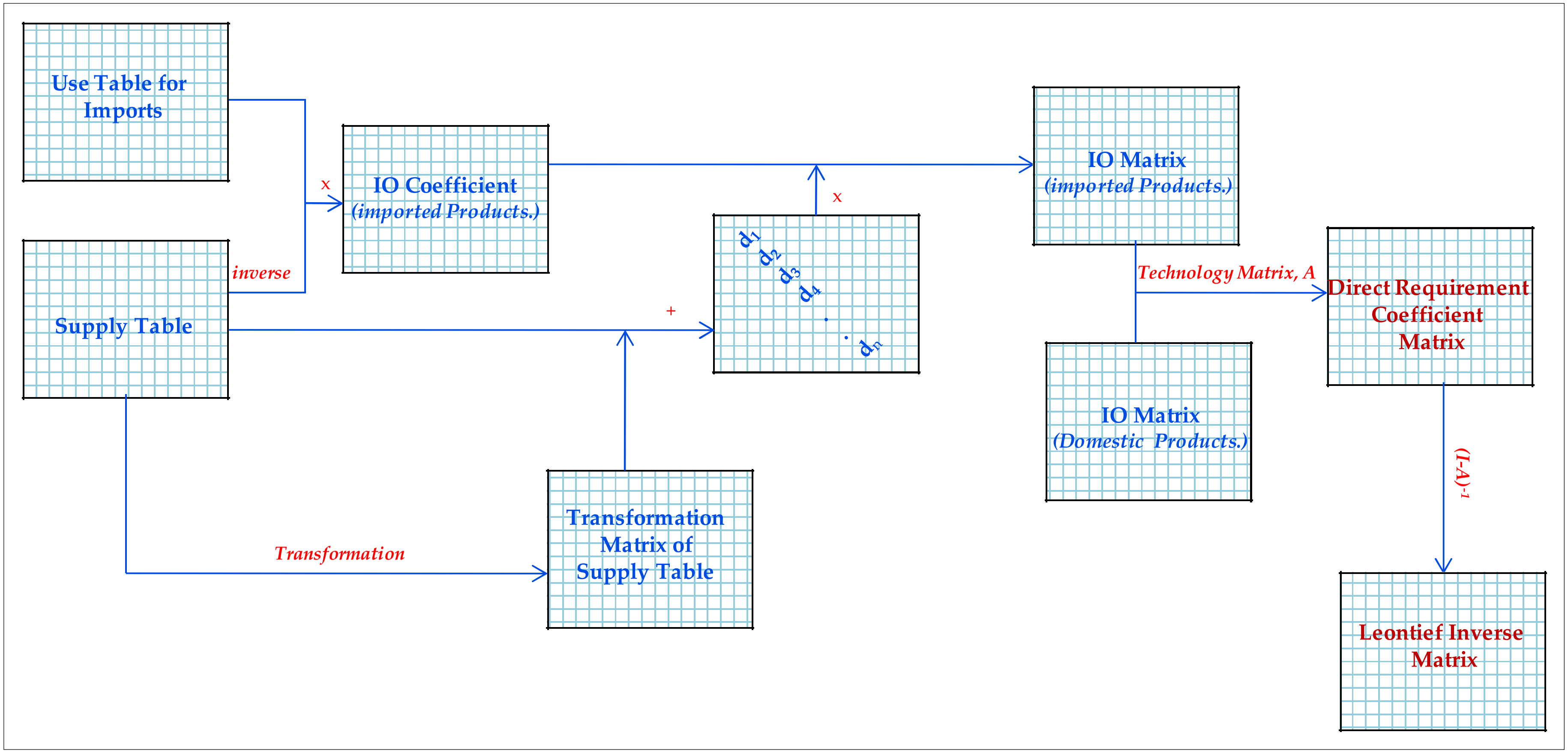
4.3.1 Derivation of Multi Regional Direct Requirement Coefficient and Leontief Inverse Matrices for Ireland

The Supply and Use Tables form a central part of the system of national accounts used as an integration framework for balancing product and services flow in national economic sectors. The intermediate part of a symmetric input-output table is square: the number of rows is equal to the number of columns. In the case of Ireland it is a 53 square matrix. The dimension can be product-by-product, industry-by-industry or product-by-industry. Product-by-product variant is preferred to industry-by-industry since it shows more homogeneous flows which are a requirement for input-output analysis (Rueda-Cantuche *et al.,* 2009). In using a product-by-product table in input-output analysis, it is assumed that each column of the table represents the input structure of the corresponding product, and that extra demand for that product leads to proportional demand of the products that are input in its production process.

The 2005 Use Table for imports is dimensioned as product by industry. It is therefore converted into a product by product matrix before being added to the symmetric input-output table for domestic product flows dimensioned as product by product. The re-derivation of the product by product tables is based on the product technology assumption which states that each product is produced in its own specific way, irrespective of the industry where it is produced. Thus, it is assumed that only one technology exists for producing each product in a given sector. In other words, each product has its own typical input structure (the proportions of products and factor inputs used to produce one unit of the product). In deriving the product-by-product table using the product technology assumption, the secondary products are transferred from the industries where they are produced to the industries of which they are the primary product. In this process, the columns are transformed from referring to industries to referring to products (EUROSTAT, 2002). The product technology model requires that for each product a primary producer is defined. The input structure of the primary producer becomes the starting point for deriving the input structure of the product. The transformation from product by industry to product by product can be explained by means of transformation matrices which are added to the original tables.

Refer to Figure 4.5 for the flow diagram of the steps undertaken in deriving a Multi Regional Input-Output (MRIO) tables (for direct requirement coefficient matrix and Leontief Inverse matrix) consisting of Irish domestic and Irish imports.

Figure 4.5: Flow Diagram showing the derivation of Multi Regional Input-Output (MRIO) tables (consisting of Irish domestic and Irish imports) for Irish direct requirement coefficient matrix and Leontief inverse matrix



The following imaginary Supply and Use and Input-Output Tables are used to describe the re-derivation analysis carried out. It shows a 2-sector economy, Electricity and Construction.

Table 4.10: 2-Sector I-O Use Table for Imports

Industry → ↓ Product	**Electricity**	**Construction**	**Final Demand**	**Total**
Electricity	0	80	50	130
Construction	60	30	130	220
Wages and salaries	60	20	-	
Operating surplus	30	70	-	
Total	150	200	180	

Table 4.11: 2-Sector I-O Supply Table

Industry → ↓ Product	**Electricity**	**Construction**	**Total**
Electricity	130	0	130
Construction	20	200	220
Wages and salaries	-	-	
Operating surplus	-	-	
Total	150	200	

Determination of the product technology is expressed mathematically as: EUROSTAT (2002);

Equation 4.5

$$\text{Use Table} = (\text{Input} - \text{Output Coefficient Matrix}) \times (\text{Supply Table})$$

Hence:

$$\text{Input} - \text{Output Coefficient Matrix} = (\text{Use Table}) \times (\text{Supply Table})^{-1}$$

From Table 4.11, given that:

$$\text{Supply Matrix} = \begin{bmatrix} 130 & 0 \\ 20 & 200 \end{bmatrix};$$

Then:

$$\text{Inverse of Supply Matrix} = \begin{bmatrix} 0.007692 & 0 \\ -0.00077 & 0.005 \end{bmatrix}$$

$$\text{Input} - \text{Output Coefficient Matrix} = \begin{bmatrix} 0 & 80 \\ 60 & 30 \\ 60 & 20 \\ 30 & 70 \end{bmatrix} \times \begin{bmatrix} 0.007692 & 0 \\ -0.00077 & 0.005 \end{bmatrix} = \begin{bmatrix} -0.06 & 0.4 \\ 0.44 & 0.15 \\ 0.44 & 0.10 \\ 0.18 & 0.35 \end{bmatrix}$$

4.3.1.1 Determination of Transformed Use Table

It is shown by EUROSTST (2002) that: (Equation 4.6)

$$\text{Transformed Use Table}_{\text{imports}}$$
$$= \left(\text{I} - \text{O Coefficient Matrix}_{\text{imports}}\right) \times [(\text{Supply Matrix}_{\text{Transformed}}) + (\text{Supply Matrix}_{\text{original}})]$$

It can be seen in the Supply Table in Table 4.11 above that Electricity produces 20 units of secondary output of products that are primary to the Construction industry. 20 units of secondary output are therefore transferred from the Electricity column to the Construction column while 0 units are transferred from Electricity to the Construction column. The transformed Supply Table therefore becomes:

Table 4.12: Transformed Supply Table

Industry → / ↓ Product	**Electricity**	**Construction**	**Total**
Electricity	0	0	0
Construction	-20	20	0
Wages and salaries	-	-	
Operating surplus	-	-	
Total	-20	20	

By adding the original Supply Table to the Transformed Supply Table, Table 4.13 below is obtained. It can be seen that Table 4.13 produces a diagonal matrix.

Table 4.13: Diagonal Transformed Table

Products → ↓ Product	**Electricity**	**Construction**	**Total**
Electricity	130	0	130
Construction	0	220	220
Wages and salaries	-	-	
Operating surplus	-	-	
Total	130	220	

Hence in Matrix Notation:

$$\text{Transformed Use Table}_{\text{imports}} = \begin{bmatrix} -0.06 & 0.4 \\ 0.44 & 0.15 \\ 0.44 & 0.10 \\ 0.18 & 0.35 \end{bmatrix} \times [\begin{bmatrix} 130 & 0 \\ 20 & 200 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ -20 & 20 \end{bmatrix}]$$

Or

$$\text{Transformed Use Table}_{\text{imports}} = \begin{bmatrix} -0.06 & 0.4 \\ 0.44 & 0.15 \\ 0.44 & 0.10 \\ 0.18 & 0.35 \end{bmatrix} \times \begin{bmatrix} 130 & 0 \\ 0 & 220 \end{bmatrix}$$

Therefore:

$$\text{Transformed Use Table}_{\text{imports}} = \begin{bmatrix} -8 & 88 \\ 57 & 33 \\ 58 & 22 \\ 23 & 77 \end{bmatrix}$$

$$\text{-----------}$$
$$[130 \quad 220]$$

Assume that the symmetric I-O matrix of domestic product flow is given by Table 4.14 below:

Table 4.14: 2-Sector I-O Symmetric Input-Output matrix

Products → ↓ Product	Electricity	Construction	Total Final use	Total
Electricity	10	20	130	160
Construction	30	40	130	200
Wages and salaries	50	60		
Operating surplus	70	80		
Total	160	200		360

Then:

$$\text{Symmetric I} - \text{O Matrix}_{\text{domestic}} = \begin{bmatrix} 10 & 20 \\ 30 & 40 \\ 50 & 60 \\ 70 & 80 \end{bmatrix}$$

$$[160 \quad 200]$$

Hence:

$$\text{Sum of domestic and imported matrices} = \begin{bmatrix} 10 & 20 \\ 30 & 40 \\ 50 & 60 \\ 70 & 80 \end{bmatrix} + \begin{bmatrix} -8 & 88 \\ 57 & 33 \\ 58 & 22 \\ 23 & 77 \end{bmatrix} = \begin{bmatrix} 2 & 108 \\ 87 & 73 \\ 108 & 82 \\ 93 & 157 \end{bmatrix}$$

$$[290 \quad 420]$$

The coefficient matrix for both domestic and imported product flow is therefore given below:

$$\text{Coefficient Matrix}_{\text{domestic} \,\&\, import} = \begin{bmatrix} 0.00689 & 0.25714 \\ 0.3 & 0.17380 \\ 0.3724 & 0.19524 \\ 0.321 & 0.37380 \end{bmatrix}$$

The direct requirement matrix, represented as Matrix A is therefore given by:

$$\text{Direct Requirement Matrix, A} = \begin{bmatrix} 0.00689 & 0.25714 \\ 0.3 & 0.17380 \end{bmatrix}$$

The Leontief Inverse Matrix which is a power series approximation of the matrix of direct requirement coefficient is expressed mathematically as:

$$I + A + A^2 + A^3 + A^4 \ldots\ldots.. = (I - A)^{-1}$$

$$\text{Leontief Inverse Matrix} = \left(\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.00689 & 0.25714 \\ 0.3 & 0.17380 \end{bmatrix}\right)^{-1}$$

$$= \begin{bmatrix} 1.111 & 0.345 \\ 0.404 & 1.336 \end{bmatrix}$$

The Leontief Inverse Table therefore becomes:

Table 4.15: Leontief Inverse Matrix

Products → ↓ Product	*Electricity*	*Construction*
Electricity	1.111	0.345
Construction	0.404	1.336

Table 4.16: Direct Requirement Coefficient D_{RC} and Total (Leontief) Requirement Coefficient T_{RC} with and without imports

Energy Supply Sectors	D_{RC} with imports	T_{RC} with imports	D_{RC} without imports	T_{RC} without imports
Coal, Peat Crude	0.00004	0.03157	0.00001	0.00100
Petroleum	0.01185	0.03830	0.00386	0.00100
Electricity and Gas	0.00344	0.02386	0.00340	0.01400

4.3.1.2 Causes of Negative Coefficients in I-O Tables

Negative coefficients in I-O tables can be caused by the following:

- **Incorrect product technology assumptions**

In cases where a product is produced in two different ways, the product technology assumption becomes inaccurate. In the chemical industry for example, different processes can be used to produce the same product. Negative coefficients therefore arise when one process uses inputs that are not used by another.

- **Recording of economic transactions rather than technological relations**

The Supply and Use Table record all transactions between local kind of-activity-unit (KAU). These are the economic transactions, and do not necessarily describe technology. For example, assuming two companies employ the same process to produce a product but one of the companies subcontracts a large part of the process while the other does the whole process in-house. The two companies will therefore show different input structures in the use table, possibly leading to negatives.

- **Aggregation and Heterogeneity in the data**

Heterogeneity in the data can also lead to negative coefficients. Heterogeneity is unavoidable because products and industries need to be aggregated in the Supply and Use Tables. In the Irish I-O tables for instance, electricity and gas are aggregated together even though they are two different products. It is clear that assuming product technology in such a case creates problems which may cause problems such as negatives in I-O coefficients.

4.4 Disaggregation Constants

A limitation of I-O analysis is the aggregation of many different products into one sector in the national I-O tables (Mongelli *et al.,* 2005), thus reducing its applicability to a specific product or product sector. For example, in the Irish I-O tables, some energy supply sectors are aggregated together either with non-energy supply sectors or other energy supply sectors (for example, the ‘Petroleum and Other Manufacturing’ sector is an aggregation of an energy supply sector, ‘Petroleum’ and non-energy supply sector ‘Other Manufacturing.’). Therefore, to address the aggregation problem a disaggregation analysis is carried out and ‘disaggregation constants’ are estimated for the 2005 I-O tables in order to split the energy supply sectors into individual energy sources and non-energy commodity sectors.

The use of the disaggregation constants has a three-fold advantage. Firstly, non-energy supply sectors are eliminated from the analysis. Secondly, it enables specific primary energy factors and energy tariffs to be used instead of average values for an aggregated energy supply sectors (for example, electricity and gas). Finally, the use of disaggregation constants helps to avoid double counting as has been illustrated in the disaggregation of NACE 40-Electricity and Gas sector.

In this thesis, the disaggregation constants were derived based on certain assumptions on Irish energy balance. The value obtains for disaggregation constants for each energy supply sector are expected to change based on the quality, year and details of data used and assumptions undertaken.

4.4.1 NACE 10-13: Coal, Peat, Crude and Metal Ore extraction

Sector 10-13 is an aggregation of energy supplies Coal, Peat and Crude and non-energy supply sector, Metal Ore Extraction. From the energy balance for Ireland obtained from the Irish Energy Statistics Databank (Sustainable Energy Authority of Ireland, 2009), total primary energy requirement for crude oil in Ireland was estimated to be 3,342ktoe. The price of crude was estimated to be equal to 322,986€/ktoe (Forbes, 2009) at 2005 tariffs

(Oanda 2009). Hence the total crude supplied across all sectors of the economy in Ireland was valued at an estimated 1,079m€. Similarly, total primary energy requirement of coal in Ireland in 2005 was estimated to be 1,880ktoe (Sustainable Energy Authority of Ireland, 2009). At a price of 0.71cents/kWh (Sustainable Energy Authority of Ireland, 2009) it is estimated that at 2005 prices (Central Statistics Office, 2009c), the price of coal was equivalent to 66,046€/ktoe. Hence the amount of coal supplied was estimated to be 124.4 m€. Likewise, the total primary energy requirement of peat in 2005 was 810ktoe (Sustainable Energy Authority of Ireland, 2009). Peat was priced at 16.6€/MWh in 2004 (SWS Group, 2005) and based on an inflated 2005 prices (Central Statistics Office, 2009c), the equivalent price of peat is estimated at 217,355€/ktoe. The total amount of peat supplied in 2005 is therefore estimated at 176m€. From the 2005 re-derived I-O tables for Ireland, the total value of supplied coal, peat, crude and metal ore extraction products from NACE 10-13 was 1,875.2m€. The total value of non-energy commodity Metal Ore Extraction is therefore 495.8 given that the total value of crude, coal and peat were respectively 1079m€, 124.4m€ and 176m€. The disaggregation constants for NACE 10-13 for the 2005 Irish I-O tables are therefore estimated to be: Crude-58%, Coal-7%, Peat-9% and Metal Ore Extraction-26%.

4.4.2 NACE 23 and 36: Petroleum and Other Manufacturing Products

Disaggregation of this sector was obtained from Wissema (2006) because data on final energy consumption of petroleum was unavailable. Wissema (2006) disaggregated the Petroleum and 'Other Manufacturing' sector in a study undertaken to construct a Social Accounting Matrix for Ireland. The analysis assumed that total demand is equal to total supply by considering the domestic production and imported oil and the production of commodities associated with ‘Other Manufacturing’. Wissema (2006) showed that NACE 23 and 36 can be disaggregated as Oil-70% and Other Manufacturing-30%.

4.4.3 NACE 40: Electricity and Gas

NACE 40 has no non-energy supply commodities; hence disaggregation constants for Electricity, Renewable Energy and Natural Gas are disaggregated from the proportional share of their total final energy use. From the Irish Energy Statistics Databank (Sustainable Energy Authority of Ireland, 2009), total final energy use of electricity, renewable energy and natural gas for 2005 are respectively: 2094ktoe, 194ktoe and 1464ktoe. Total final energy use of coal and peat was also estimated to be 435ktoe and 274ktoe (Sustainable Energy Authority of Ireland, 2009). To avoid double counting, the proportion of renewable energy, natural gas, coal and peat in the electricity mix in 2005 is also deducted from the total final use of electricity. In 2005, renewable energy and natural gas constituted 9% and 46% of the overall fuel mix by fuel type for electricity generation in Ireland while coal and peat constituted 24% and 8% respectively (Commission for Energy Regulation, 2006). Hence, it follows that, of the 2,094ktoe of electricity used, 1822ktoe representing 189ktoe of renewable energy and 963ktoe of natural gas as well as 503ktoe and 166ktoe of coal and peat respectively are subtracted from the total final use of electricity. NACE 40-Electricity and Gas is now disaggregated in the proportion: Electricity-273ktoe, Renewable Energy-194ktoe and Natural Gas-1464ktoe. Hence the disaggregation constants for NACE 40 become: Electricity-14%, Renewable Energy-10% and Natural Gas-76%.

A summary of the 2005 disaggregation constants for the energy supply sectors are shown in Table 4.17 below:

Table 4.17: Summary of 2005 Energy Sectors Disaggregation Constants for Ireland

I-O Sector	Aggregated Energy Supply Sectors	Disaggregated Energy Supply Sub-Sectors	Disaggregated Constants C_e
10-13	Mining and Quarrying	Peat	0.09
		Crude Oil	0.58
		Coal	0.07
23 & 36	Petroleum and 'Other Manufacturing'	Petroleum	0.70
40	Electricity and Gas	Electricity	0.14
		Natural Gas	0.76
		Renewable Energy	0.10

4.5 Construction Sector Indirect Embodied Energy and CO_2-eq Intensities due to Domestic and Imported Goods and Services

The direct and Leontief input coefficients of the economy wide I-O tables are used to derive I-O indirect sectoral embodied energy intensities in the construction sector. This methodology is widely used and described in literature (see inter alia Bullard *et al.,* 1978, Treloar, 1997 and 1998). In summary, the approach involves using Irish I-O tables (Central Statistics Office, 2009b), average energy tariffs (Sustainable Energy Authority of Ireland, 2009) and primary energy factors (Sustainable Energy Authority of Ireland, 2007) to determine total I-O sectoral embodied and direct I-O sectoral embodied energy intensities per unit monetary value of construction sector output. Indirect I-O sectoral embodied energy intensity is calculated as the difference between the total I-O sectoral embodied and direct I-O sectoral embodied energy intensities. The I-O sectoral indirect embodied energy intensity is converted to I-O sectoral indirect embodied CO_2-eq intensities by applying Irish emission factors published by Sustainable Energy Authority of Ireland (2003).

Treloar (1997 and 1998) showed that the I-O sectoral direct embodied energy intensity, [GJ/€] of the construction sector can be evaluated using Equation 4.7 below:

Equation 4.7:

$$\mathrm{I-O\ Sectoral\ Direct\ Embodied\ Energy\ Intensity} = \sum_{e=1}^{E}(\mathrm{D}_{\mathrm{RC}_e} \times \mathrm{T}_e \times \mathrm{P.E.F}_e)$$

Where:

$\mathrm{D}_{\mathrm{RC}_e}$ = Direct requirement coefficients of energy supply sector e [€/€]

E = the total number of energy supply sectors, e in the I-O table

T_e = Average energy Tariff [GJ/€]

$\mathrm{P.E.F}_e$ = Primary Energy Factor of energy supply sector e [dimensionless]

Treloar (1997 and 1998) also showed that the I-O sectoral total embodied energy intensity, [GJ/€] of the construction sector can be evaluated using Equation 4.8 below:

Equation 4.8

$$\mathrm{I-O\ sectoral\ Total\ Embodied\ Energy\ Intensity} = \sum_{e=1}^{E}(\mathrm{T}_{\mathrm{RC}_e} \times \mathrm{T}_e \times \mathrm{P.E.F}_e)$$

Where:

$\mathrm{T}_{\mathrm{RC}_e}$ = Total requirement coefficients [€/€]

In this thesis, Equations 4.7 and 4.8 above are re-adjusted using disaggregation constants, C to derive the benefits mentioned in Section 4.4. The I-O sectoral direct embodied energy intensity and I-O sectoral total embodied energy intensity of Irish construction are therefore estimated from Equations 4.9 and 4.10 respectively.

Equation 4.9:

I-O Sectoral Direct Embodied Energy Intensity $= \sum_{e=1}^{E}(\mathrm{D}_{\mathrm{RC}_e} \times \mathrm{T}_e \times \mathrm{P.E.F}_e \times \mathrm{C}_e)$

Where:

C_e = Disaggregation constant for energy sub-sector e

Equation 4.10:

$$\mathrm{I-O\ Sectoral\ Total\ Embodied\ Energy\ Intensity} = \sum_{e=1}^{E}(\mathrm{T}_{\mathrm{RC}_e} \times \mathrm{T}_e \times \mathrm{P.E.F}_e \times \mathrm{C}_e)$$

I-O sectoral indirect embodied energy intensity for the construction sector was estimated to be 0.01779GJ/€. This is the difference between 0.01976GJ/€ (the I-O sectoral total embodied energy intensity) and 0.00197GJ/€ (the I-O sectoral direct embodied energy intensity). The total embodied energy intensity of Irish construction is therefore estimated to be 0.018566GJ/€ (that is, the sum of the direct sub-sectoral embodied energy intensity and I-O sectoral indirect embodied energy intensity).

To estimate I-O sectoral direct and I-O sectoral total embodied CO_2-eq intensities, national emission factors I_e are also applied to convert the embodied energy intensities to embodied

CO_2-eq intensities. Hence the I-O sectoral direct embodied CO_2-eq intensity and I-O sectoral total embodied CO_2-eq intensity of construction are re-written respectively as shown in Equations 4.11 and 4.12 below:

Equation 4.11:

$$\mathrm{I-O\ Sectoral\ Direct\ Embodied\ CO_{2-eq}\ Intensity} = \sum_{e=1}^{E}(D_{RC_e} \times T_e \times P.E.F_e \times C_e \times I_e)$$

Where:

I_e= Emissions intensity of energy supply sector, e.

And

Equation 4.12:

$$\mathrm{I-O\ Sectoral\ Total\ embodied\ CO_{2-eq}\ Intensity} = \sum_{e=1}^{E}(T_{RC_e} \times T_e \times P.E.F_e \times C_e \times I_e)$$

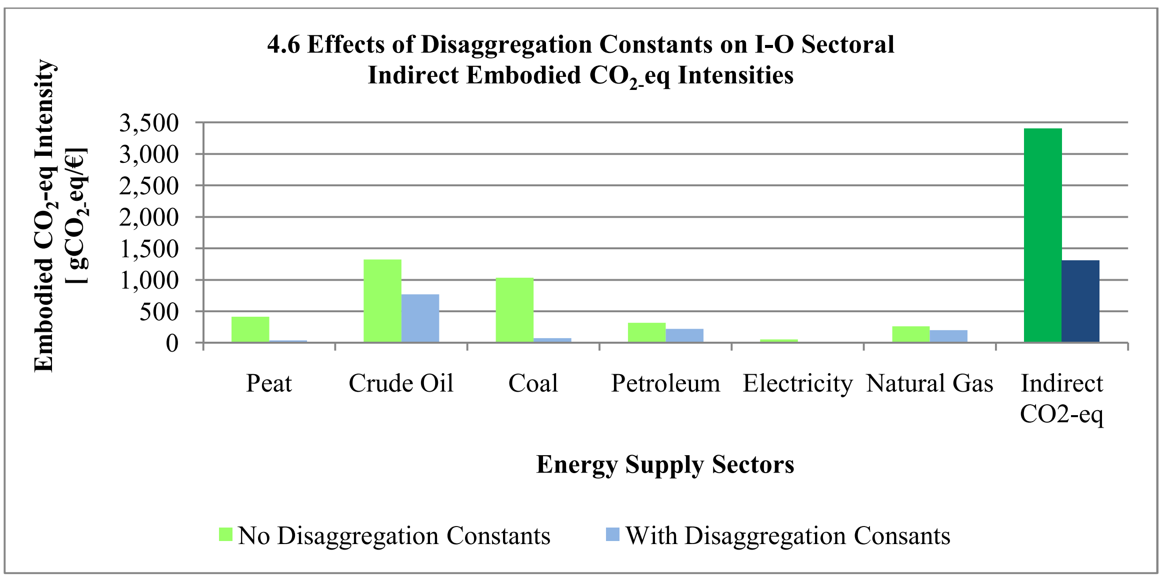
Indirect sectoral embodied CO_2-eq intensity of construction can therefore be estimated from the difference between the I-O sectoral total and I-O sectoral direct embodied CO_2-eq intensities of construction which is given in Equation 4.13 below:

Equation 4.13:

$$\mathrm{I-O\ Sectoral\ Indirect\ embodied\ CO_{2-eq}\ Intensity} =$$

$$[\sum_{e=1}^{E}(T_{RC_e} \times T_e \times P.E.F_e \times C_e \times I_e)] - [\sum_{e=1}^{E}(D_{RC_e} \times T_e \times P.E.F_e \times C_e \times I_e)]$$

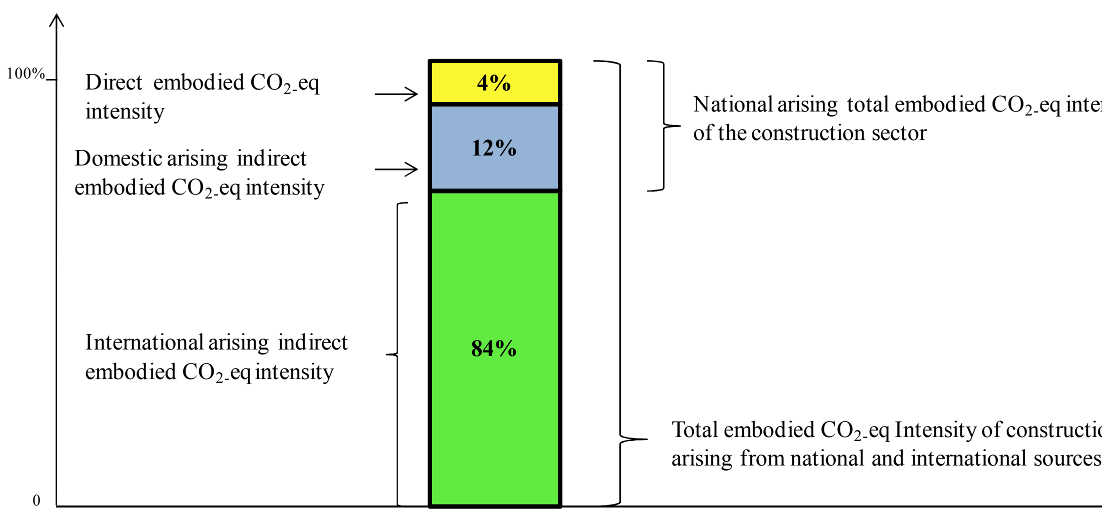
The importance in using disaggregation constants in evaluating I-O sectoral energy and emissions intensities can be observed in the variations in the results presented in Figure 4.6 below. For each of the energy supply sectors there is an increase in indirect I-O embodied CO_2-eq intensities when no disaggregation constants are used. In calculating I-O sectoral embodied CO_2-eq intensities for example, it is observed that not including disaggregation constants results in an overestimation of more than 2.6 times compared to when disaggregation constants are used. The increases in indirect emissions can be attributed to the inclusion of non-energy commodities in the analysis and double counting in energy inputs.



I-O sectoral indirect embodied CO_2-eq intensity of Irish construction is estimated to be 1,308gCO_2-eq/€. This is calculated from Equation 4.13 where Irish emission factor are applied to the I-O sectoral total and direct sub-sectoral embodied energy intensities. The GHG contribution to the I-O sectoral indirect embodied CO_2-eq intensity was dominated by

CO_2 as was the case in the sub-sector direct embodied CO_2-eq intensity; contributing approximately 99% of the total. The estimated I-O indirect sectoral embodied CO_2-eq intensity of 1,308gCO_2-eq/€ can be broken down to 160gCO_2-eq/€ of domestic arising emissions and 1,148gCO_2-eq/€ internationally arising emissions. The nationally arising indirect emissions therefore correspond to 12% of indirect emissions. International arising indirect embodied CO_2-eq intensities dominates the total embodied emissions and account for 84% of total embodied CO_2-eq intensities of Irish construction. This is illustrated in Figure 4.7 below.

Figure 4.7 Percentage shares of national and international sources of embodied CO_2-eq intensities

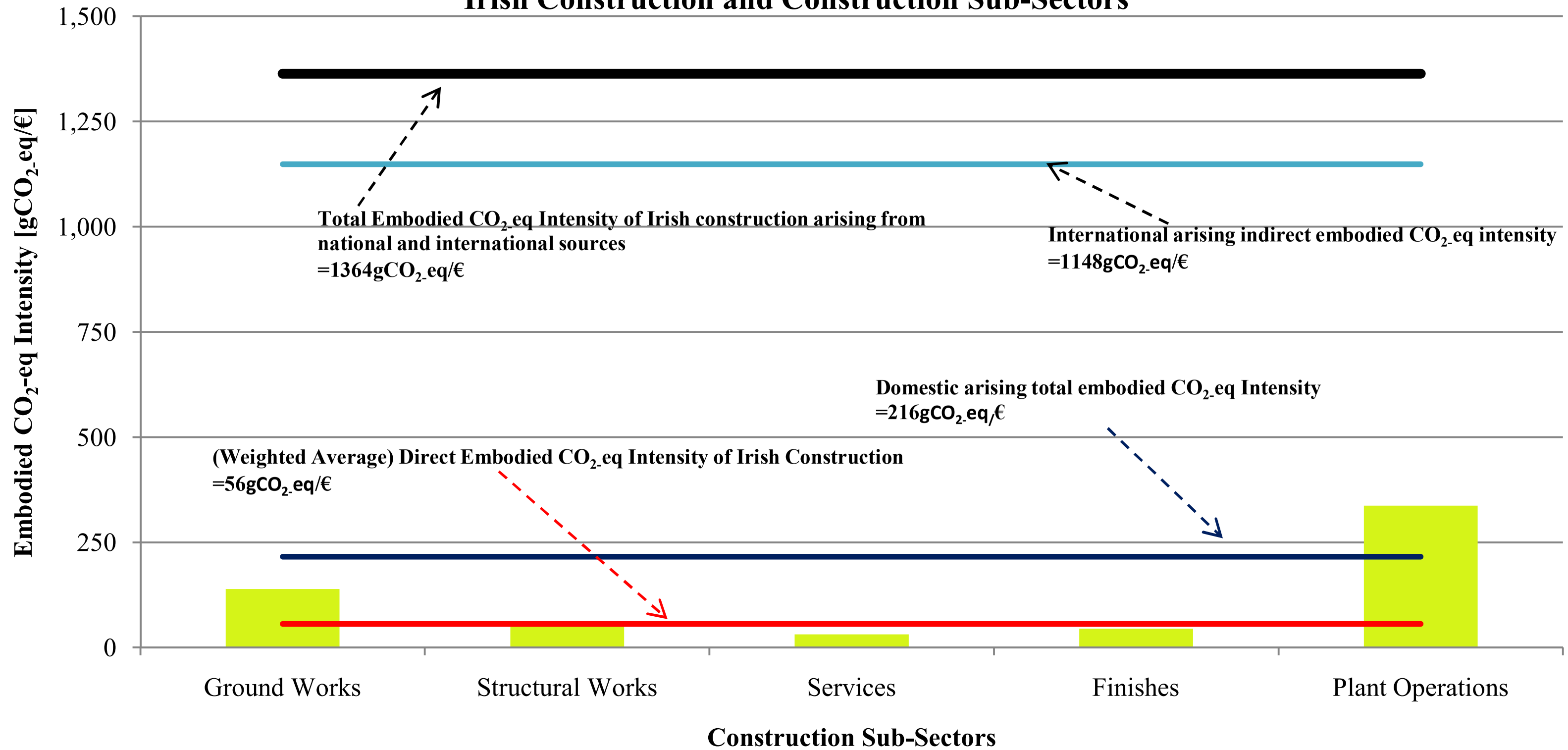


The total embodied CO_2-eq intensities of the Irish construction sector is calculated as the sum of the direct sub-sectoral embodied CO_2-eq intensity and I–O sectoral indirect embodied CO_2-eq intensity (the methodological process is illustrated in the flowchart diagram in Figure 3.2). The total embodied CO_2-eq intensities of the Irish construction is estimated to be 1,364gCO_2-eq/€ as shown in Figure 4.8 below. Domestic arising total embodied CO_2-eq intensity of the Irish construction was estimated to be 215gCO_2-eq/€ or 16% of the total embodied emissions. This comprises of 56gCO_2-eq/€ or 4% of direct sub-sectoral embodied emissions and 160gCO_2-eq/€ or 12% of I-O sectoral indirect embodied emissions. I-O direct embodied CO_2-eq intensity was estimated to be 136gCO_2-eq/€ as opposed to a direct sub-sectoral embodied CO_2-eq intensity of 56gCO_2-eq/€. It is assumed that because the I-O data was constructed from a variety of sources using average data, the sub-sectoral direct embodied CO_2-eq intensity is more accurate because it was calculated from data collected on site by construction firms for direct energy used.

The results obtain for national and arising sources of emissions in this thesis differ from that obtained from similar study undertaken Acquaye *et al.* (2010). For instance, it is estimated in this study that 16% of total emissions was domestically arising compared to 11.7% in Acquaye *et al.* (2010). While the calculations in this study was undertaken using the 2005 Irish I-O tables and construction sub-sector data from 2003 to 2006, the calculations in Acquaye *et al.* (2010) used the 2000 Irish I-O tables and 2005 construction sub-sector data, hence the difference.

The large percentage of international arising indirect energy intensity may be the result of energy used in the production of building materials which are mostly imported into Ireland and energy embodied in other upstream goods and services. It is clearly seen that indirect embodied CO_2-eq emissions arising from foreign countries is a major source of emissions along the construction supply chain. Knowledge of the sources of indirect emissions provides additional information for decision making by designers and policy makers by considering total upstream impacts of construction related activities. The Central Statistics Office (2004) also estimates that 56% of Irish imports are from the European Union, hence an understanding of the sources of energy inputs and emissions are also important from an EU policy perspective.

Figure 4.8: Direct and Total Embodied CO_2-eq Intensity of Irish Construction and Construction Sub-Sectors



CHAPTER 5:

Stochastic Hybrid Embodied CO_2-eq Intensity Analysis

5.0 Overview

The development of embodied CO_2-eq analysis and life cycle assessment (LCA) has progressed significantly in recent years, and LCA has become a mainstream practice in many industries as evidenced by the development of the ISO 14040 and 14044 Life Cycle Assessment Environmental Standards. However, it is recognized that due to weaknesses in gathering data on product-related energy use and emissions, embodied energy values are probabilistic (Menzies *et al.*, 2007). For example: designers and contractors are currently unable to obtain embodied emissions in the products they employ (apart from in exceptional circumstances); and the use of sectoral emissions intensities (derived using input-output techniques) to estimate emissions for a particular product or process is normal practice, although the intensity relates to a wide range of products and processes aggregated into one sector. Despite these uncertainties regarding the applicability of data to the product being analysed, it is noted by commentators (*inter alia* Shipworth, 2002 and Shih-Chi *et al.,* 2005) that even with the recent methodological improvements in embodied energy and CO_2-eq analysis, the general approach to estimating embodied emissions and energy remains deterministic, thus obscuring both the uncertainty and true variability in the embodied energy and life cycle assessment results.

Best practice in embodied emissions analysis involves a hybrid approach incorporating both process and input-output analysis (*inter alia* Joshi, 2000; Lenzen *et al.*, 2002; Crawford, 2005 and Suh *et al.*, 2005). These two approaches rely respectively on process-related data and national sectoral economic data combined with environmental accounts to give emissions per unit monetary output from the sector (Refer to Section 2.3.3). For process data, uncertainties arise due to variations in manufacturing processes and supply chains, measurement error and the use of out-of-date data. In the case of input-output data, a significant source of error is due to its highly aggregated nature: for example, construction sector emissions intensity is equally applied to house building and motorway construction.

A stochastic approach is therefore adopted in the hybrid embodied CO_2-eq intensity ($HECO_2$-eqI) analysis in order to incorporate variability in input data and derive distributions which convey more information about the $HECO_2$-eqI characteristics of buildings and can form the basis for targeted policies designed to reduce the overall emissions in an industry sector or market segment. Such a stochastic $HECO_2$-eqI relationship presented in Equation 3.1 (Section 3.2.1) is implemented by Monte Carlo simulation requiring the derivation of stochastic input variables.

The analysis is done using embodied emissions intensity (in terms of $HECO_2$-eqI) rather that embodied emissions (in terms of $HECO_2$-eq) since the analysis forms the basis for the development of building sector emissions policies. The use of embodied emissions intensity provides a standardized way of comparing similar buildings.

5.1 Stochastic Input Variables into Hybrid Model

5.1.1 Process Embodied CO_2-eq Intensities

Energy and emissions data for buildings materials process embodied CO_2-eq intensities ($PECO_2$-eqI_{mat}) were obtained from the Inventory of Carbon and Energy database, ICE v1.6a (Sustainable Energy Research Group, 2008) and fitted into a probability density function and the distributions ranked according to Kolmogorov Smirnov goodness of fit. Using the statistical parameters of the number one ranked fitted distribution, a set of 10,000 random CO_2-eq intensities are then generated for each of the building materials and used as input variables for the stochastic modelling.

Derived process embodied CO_2-eq intensity distributions of some common building materials, the statistical properties of the distributions and the probability density function of the fitted distribution are shown in Figures 5.1-5.6 below. It is hoped that this work however constraint by time and data would form the basis for further work in the built environment given time and an exhaustive data sets in using stochastic hybrid embodied CO_2-eq intensity analysis as a policy development tool.

5.1.1.1 Embodied CO_2-eq Intensity Distribution of Steel:

Type of Distribution: Kumaraswamy [α_1=2.1; α_2=99.0; a=0.22 and b=20.0]

Probability Density Function:

$$f(x) = \frac{\alpha_1 \alpha_2 z^{\alpha_1 - 1}(1 - z^{\alpha_1})^{\alpha_2 - 1}}{(b - a)}$$

Where:

α_1= Continuous shape parameter ($\alpha_1 > 0$)

α_2= Continuous shape parameter ($\alpha_2 > 0$)

a, b= Continuous boundary parameter ($a < b$)

Figure 5.1: Embodied CO_2-eq Intensity Distribution of Steel

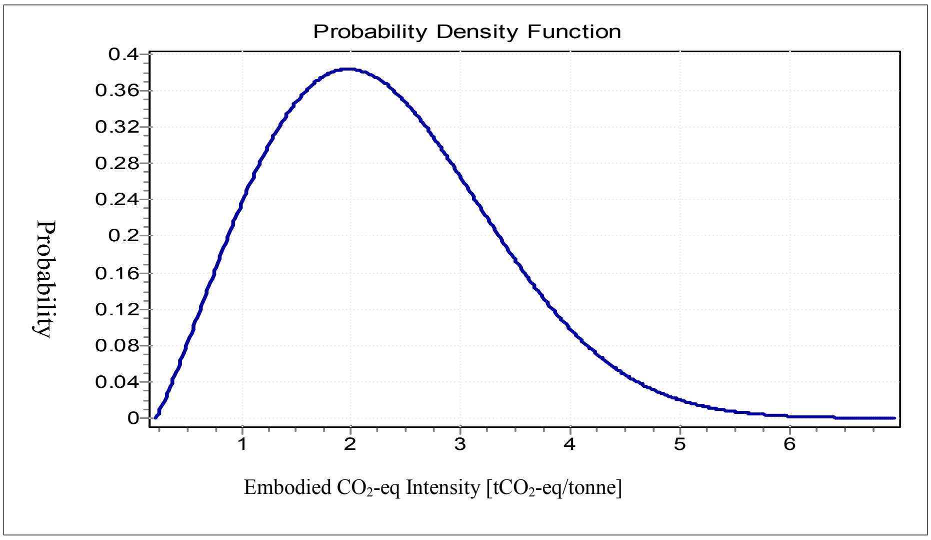


Table 5.1: Other Statistical Parameters

Min tCO_2-eq /tonne	Max tCO_2-eq /tonne	Mode tCO_2-eq /tonne	Mean tCO_2-eq /tonne	Variance tCO_2-eq /tonne	St. Dev tCO_2-eq /tonne	Coeff of Var	Skewness	Class Interval tCO_2-eq /tonne
0.22	7.0	2.0	2.3	1.0	1.0	0.44	0.52	1

5.1.1.2 Embodied CO_2-eq Intensity Distribution of Concrete

Type of Distribution: Dagum [k=2.1; α=0.84; β=0.95 and γ=0.03]

Probability Density Function:

$$f(x) = \frac{ak\frac{(x-\gamma)}{\beta}^{k\alpha-1}}{\beta\left((1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$$

k = Continuous shape parameter ($k > 0$)

α = Continuous shape parameter ($\alpha > 0$)

β = Continuous scale parameter ($\beta > 0$)

γ = Continuous location parameter ($\gamma \equiv 0$ yields the 3-parameter Dagum distribution)

Figure 5.2: Embodied CO_2-eq Intensity Distribution of Concrete

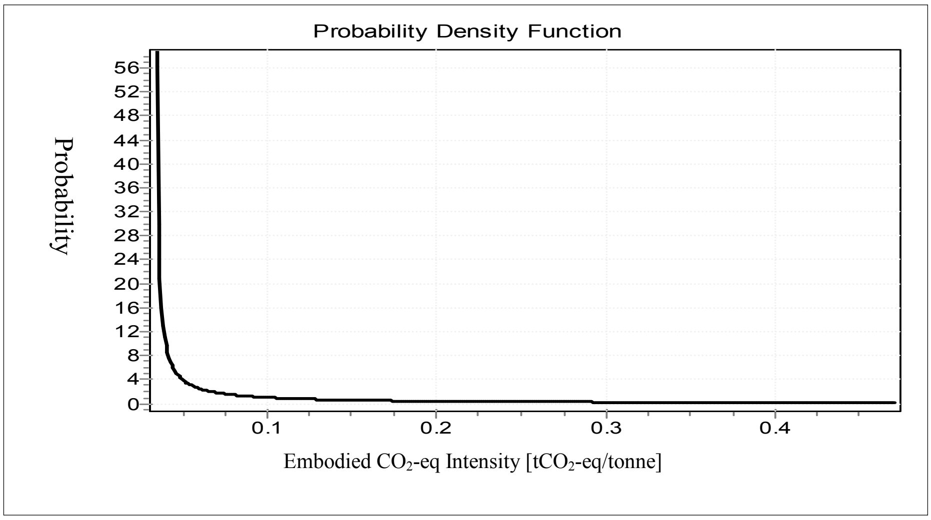


Table 5.2: Other Statistical Parameters

Min tCO_2-eq /tonne	Max tCO_2-eq /tonne	Mode tCO_2-eq /tonne	Mean tCO_2-eq /tonne	Class Interval tCO_2-eq /tonne
0.03	3.41	0.03	0.24	0.1

5.1.1.3 Embodied CO_2-eq Intensity Distribution of Insulation

Type of Distribution: Burr [k=1.5; α=1.8; β=1.7 and γ=0]

Probability Density Function:

$$f(x) = \frac{ak\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\beta\left((1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$$

Where

k = Continuous shape parameter ($k > 0$)

α = Continuous shape parameter ($\alpha > 0$)

β = Continuous scale parameter ($\beta > 0$)

γ = Continuous location parameter ($\gamma \equiv 0$ yields the three parameter Burr distribution)

Figure 5.3: Embodied CO_{2}-eq Intensity Distribution of Insulation

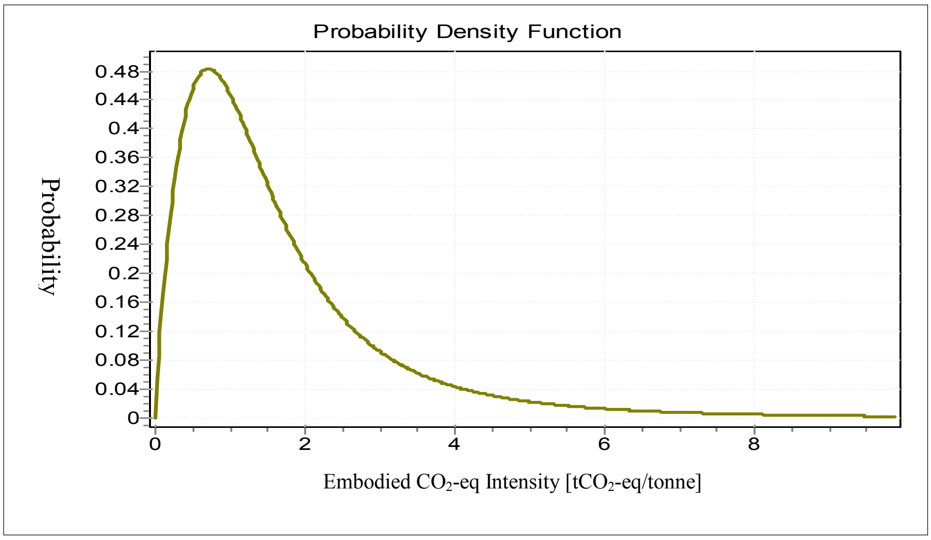


Table 5.3: Other Statistical Parameters of Distribution:

Min tCO_{2}-eq /tonne	Max tCO_{2}-eq /tonne	Mode tCO_{2}-eq /tonne	Mean tCO_{2}-eq /tonne	Variance tCO_{2}-eq /tonne	St. Dev tCO_{2}-eq /tonne	Coeff of Var	Class Interval tCO_{2}-eq /tonne
0	80	0.7	1.8	6.4	2.5	1.4	2

5.1.1.4 Embodied CO_{2}-eq Intensity Distribution of Timber

Type of Distribution: Kumaraswamy [α_1=0.34; α_2=1.7; a=0.27 and b=3.9]

Probability Density Function:

$$f(x) = \frac{\alpha_1 \alpha_2 z^{\alpha_1 - 1}(1 - z^{\alpha_1})^{\alpha_2 - 1}}{(b - a)}$$

Where:

α_1= Continuous shape parameter ($\alpha_1 > 0$)

α_2= Continuous shape parameter ($\alpha_2 > 0$)

a, b= Continuous boundary parameter ($a < b$)

Figure 5.4: Embodied CO_2.eq Intensity Distribution of Timber

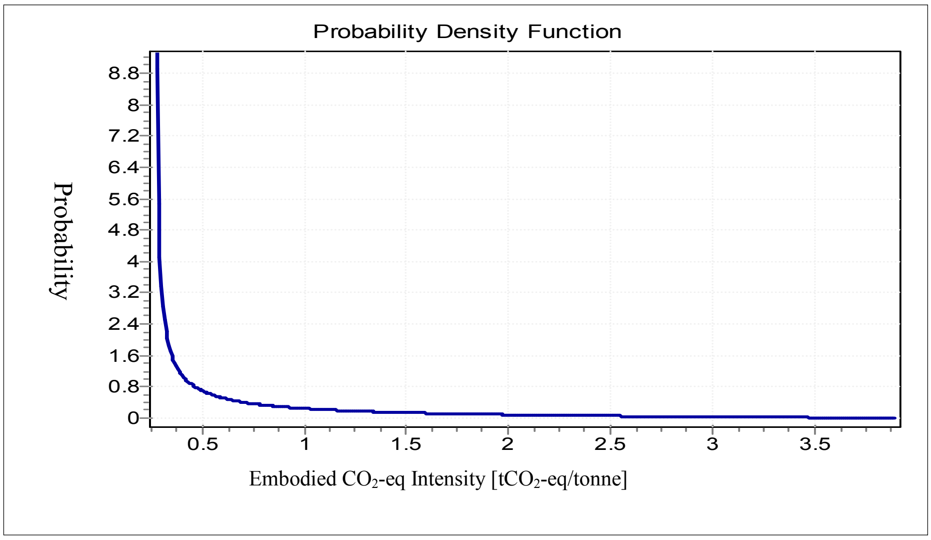


Table 5.4: Other Statistical Parameters

Min tCO_2.eq /tonne	Max tCO_2.eq /tonne	Mode tCO_2.eq /tonne	Mean tCO_2.eq /tonne	Variance tCO_2.eq /tonne	St. Dev tCO_2.eq /tonne	Coeff of Var	Skewness	Class Interval tCO_2.eq /tonne
0.27	3.9	0.27	0.74	0.47	0.68	0.93	1.9	0.5

5.1.1.5 Embodied CO_2.eq Intensity Distribution of Stone

Type of Distribution: Gamma [=0.32; β=0.21 and γ=0.06]

Probability Density Function:

$$f(x) = \frac{(x-\gamma)^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)} \exp\left(\frac{\gamma - x}{\beta}\right)$$

α = Continuous shape parameter ($\alpha > 0$)

β = Continuous scale parameter ($\beta > 0$)

γ = Continuous location parameter ($\gamma \equiv 0$ yields the two parameter Gamma distribution)

Figure 5.5: Embodied CO_2-eq Intensity Distribution of Stone

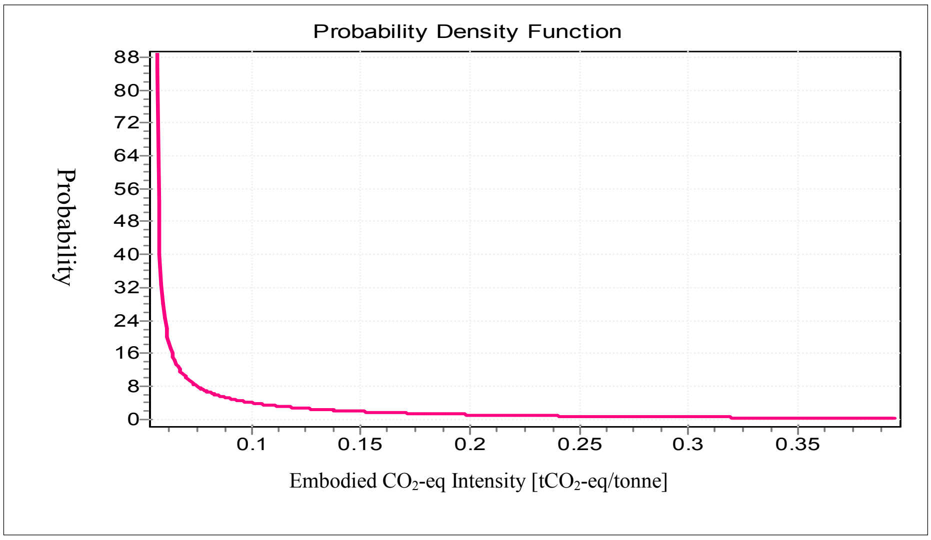


Table 5.5: Other Statistical Parameters

Min tCO_2-eq /tonne	Max tCO_2-eq /tonne	Mode tCO_2-eq /tonne	Mean tCO_2-eq /tonne	Variance tCO_2-eq /tonne	St. Dev tCO_2-eq/tonne	Skewness	Class Interval tCO_2-eq /tonne
0.06	1.81	0.06	0.12	0.01	0.12	3.6	0.05

5.1.1.6 Embodied CO_2-eq Intensity Distribution of Brick

Type of Distribution: Kumaraswamy [α_1=0.28; α_2=1.7; a=0.18 and b=2.8]

Probability Density Function:

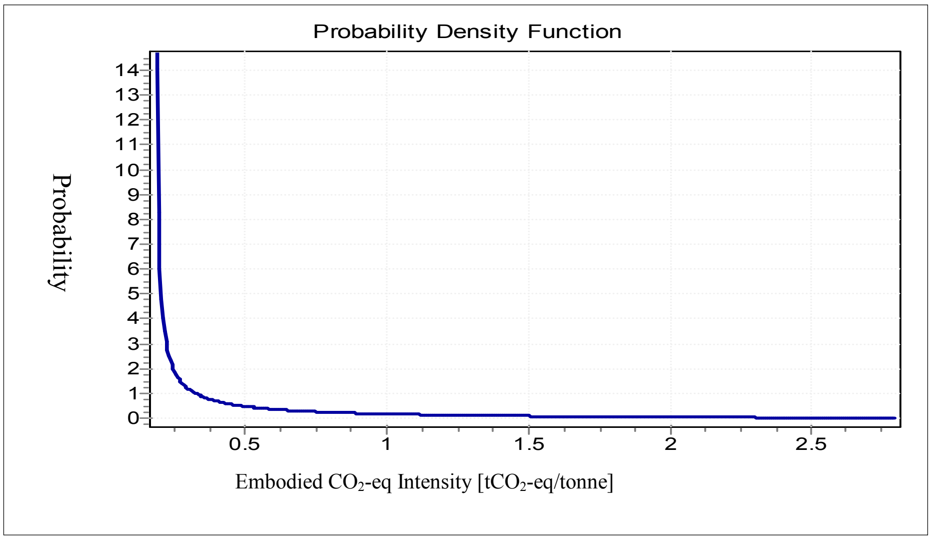
$$f(x) = \frac{\alpha_1 \alpha_2 z^{\alpha_1 - 1}(1 - z^{\alpha_1})^{\alpha_2 - 1}}{(b - a)}$$

α_1= Continuous shape parameter ($\alpha_1 > 0$)

α_2= Continuous shape parameter ($\alpha_2 > 0$)

a, b= Continuous boundary parameter ($a < b$)

Figure 5.6: Embodied CO_2-eq Intensity Distribution of Brick



5.6: Other Statistical Parameters

Min tCO_2-eq /tonne	Max tCO_2-eq /tonne	Mode tCO_2-eq /tonne	Mean tCO_2-eq /tonne	Variance tCO_2-eq tonne	St. Dev tCO_2-eq /tonne	Skewness	Class Interval tCO_2-eq /tonne
0.18	2.8	0.18	0.45	0.2	0.45	2.3	0.5

5.1.2 Direct Sub-Sectoral Embodied CO_2-eq Intensities

Direct sub-sector embodied CO_2-eq intensities of construction activities are treated as stochastic variables. The distributions for the direct sub-sector CO_2-eq intensities of the Irish construction sector are derived from disaggregated micro data of electricity and fuel used by construction firms in the Census of Building and Construction from 2003-2006 for each of the five sub-sectors. The weighted distributions for Sub-Sectors 1-5 are presented in Figures 5.7 to 5.11. The distribution and statistical parameters are then used to generate random input parameters in the Monte Carlo modelling of $HECO_2$-eqI.

5.1.2.1 Direct Embodied CO_{2eq} Intensity Distribution of Sub-Sector 1, i_{d1}: Ground Works

Type of Distribution: Generalized Gamma [k=1.2; α=0.56; β=6.6 and γ=0.02]

Probability Density Function:

$$f(x) = \frac{k(x-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} \exp\left(\frac{(\gamma - x)}{\beta}\right)^{k}$$

k = Continuous shape parameter (k > 0)

α = Continuous shape parameter (α > 0)

β = Continuous scale parameter (β > 0)

γ = Continuous location parameter (γ ≡ 0 yields the three parameter Generalized Gamma distribution)

Figure 5.7: Direct Embodied CO_2-eq Intensity Distribution: Ground Works

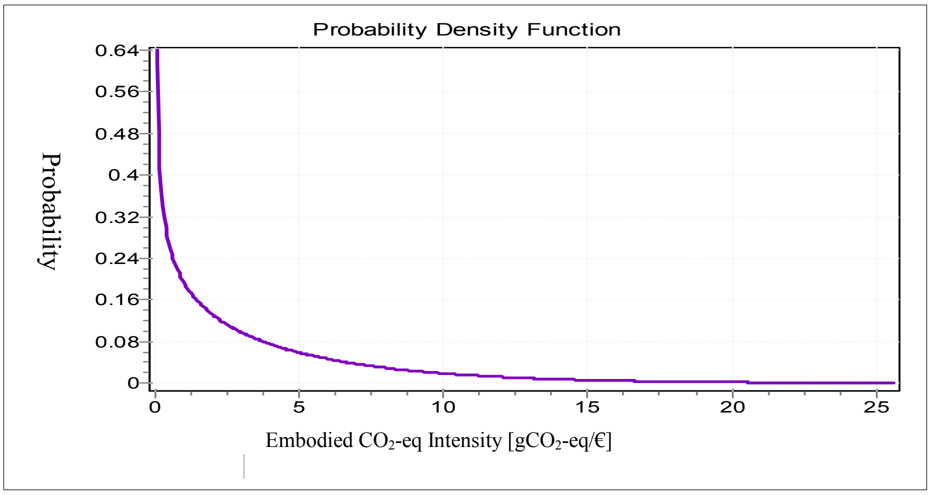


Table 5.7: Other Statistical Parameters:

Min gCO₂.eq/€	Max gCO₂.eq/€	Mode gCO₂.eq/€	Mean gCO₂-eq/€	St. Dev gCO₂.eq/€	Coeff of Var	Skewness	Class Interval gCO₂.eq/€
0.02	51	0.02	3.7	4.3	1.2	2.2	5

5.1.2.2 Direct Embodied CO_2-eq Intensity Distribution of Sub-Sector 2: Structural Works, i_{d2}

Type of Distribution: Log-Logistic [α=1.1; β=0.02 and γ=2.4×10^{-6}]

Probability Density Function:

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{-2}$$

Where

α = Continuous shape parameter ($\alpha > 0$)

β = Continuous scale parameter ($\beta > 0$)

γ = Continuous location parameter ($\gamma \equiv 0$ yields the two parameter Log-Logistic distribution)

Figure 5.8: Direct Embodied CO_2-eq Intensity Distribution: Structural Works

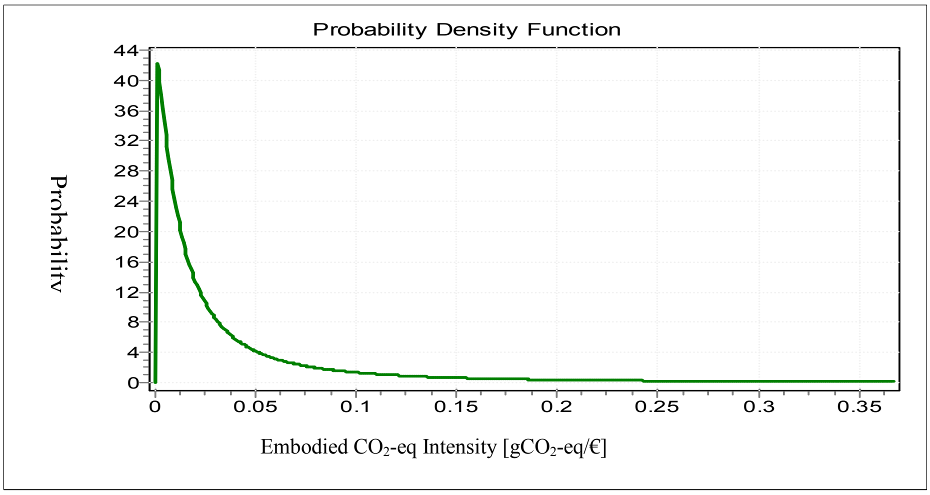


Table 5.8: Other Statistical Parameters:

Min gCO$_2$-eq/€	Max gCO$_2$-eq/€	Mode gCO$_2$-eq/€	Mean gCO$_2$-eq/€
2.4×10^{-6}	676	7.3×10^{-4}	0.3

5.1.2.3 Direct Embodied CO_2-eq Intensity Distribution of Sub-Sector 3, i_{d3}: Services

Type of Distribution: Frechet [α=1.0; β=0.02 and γ=0]

Probability Density Function:

$$f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x-\gamma}\right)^{\alpha+1} \exp\left(-\left(\frac{\beta}{x-\gamma}\right)^{\alpha}\right)$$

Where

α = Continuous shape parameter ($\alpha > 0$)

β = Continuous scale parameter ($\beta > 0$)

γ = Continuous location parameter ($\gamma \equiv 0$ yields the 2-parameter Frechet distribution)

Figure 5.9: Direct Embodied CO_2-eq Intensity Distribution: Services

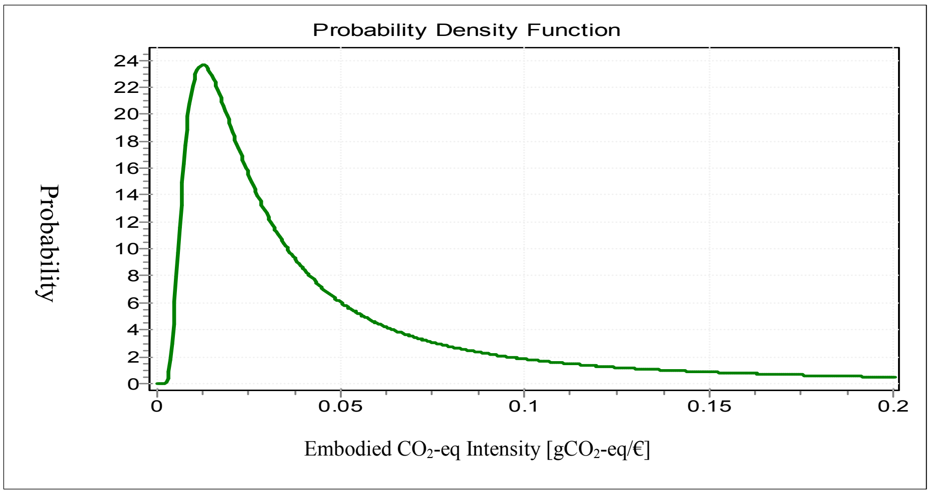


Table 5.9: Other Statistical Parameters:

Min gCO2-eq/€	Max gCO2-eq/€	Mode gCO2-eq/€	Mean gCO2-eq/€
0.001	690	0.001	0.48

5.1.2.4 Direct Embodied CO_2-eq Intensity Distribution of Sub-Sector 4, i_{d4}: Finishes

Type of Distribution: Dagum [k=0.73; α=1.6; β=0.39 and γ=0]

Probability Density Function:

$$f(x) = \frac{ak\frac{(x-\gamma)}{\beta}^{k\alpha-1}}{\beta\left((1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}}$$

k = Continuous shape parameter ($k > 0$)

α = Continuous shape parameter ($\alpha > 0$)

β = Continuous scale parameter ($\beta > 0$)

γ = Continuous location parameter ($\gamma \equiv 0$ yields the three parameter Dagum distribution)

Figure 5.10: Direct Embodied CO_2-eq Intensity Distribution: Finishes

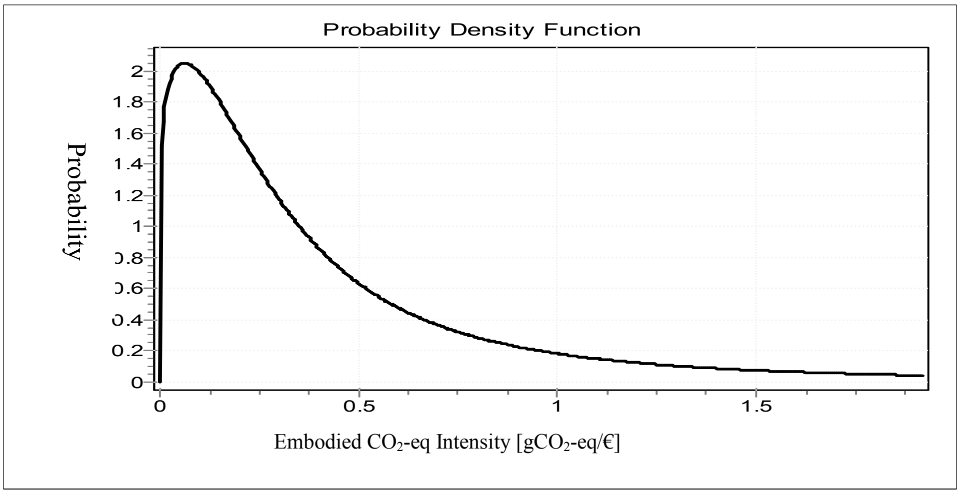


Table 5.10: Other Statistical Parameters of Distribution:

Min gCO_2-eq/€	Max gCO_2-eq/€	Mode gCO_2-eq/€	Mean gCO_2-eq/€
0.06	643	0.06	0.68

5.1.2.5 Direct Embodied CO_2-eq Intensity Distribution of Sub-Sector 5, i_{d5}: Plant Operations

Type of Distribution: Frechet [α=1.1; β=11.0 and γ=−2.9]

Probability Density Function:

$$f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x-\gamma}\right)^{\alpha+1} \exp(-\left(\frac{\beta}{x-\gamma}\right)^{\alpha})$$

Where

α = Continuous shape parameter ($\alpha > 0$)

β = Continuous scale parameter (β > 0)

γ = Continuous location parameter (γ ≡ 0 yields the two parameter Frechet distribution)

Figure 5.11: Direct Embodied CO_2-eq Intensity Distribution: Plant Operations

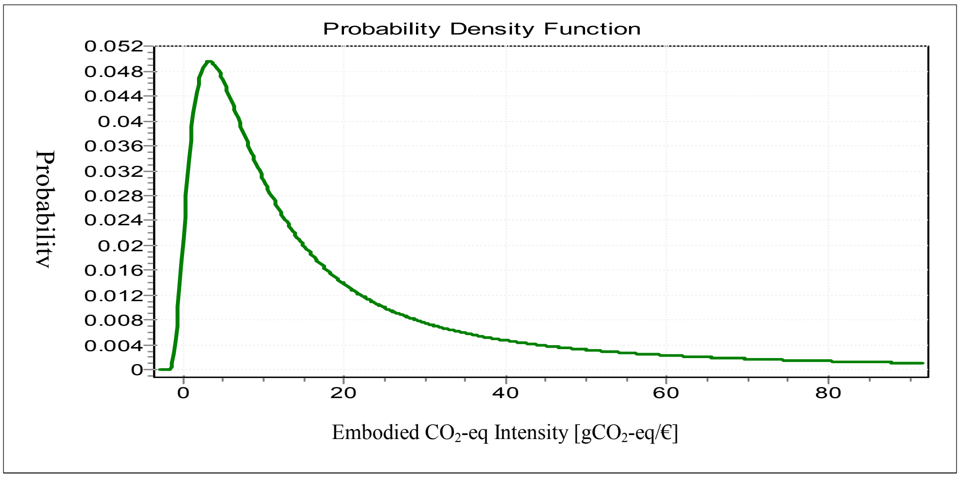


Table 5.11: Other Statistical Parameters of Distribution:

Min gCO_2.eq/€	Max gCO_2.eq/€	Mode gCO_2.eq/€	Mean gCO_2.eq/€
0.01	150	3.2	15

5.2 Deterministic Input Variables to Hybrid Model

I-O sectoral indirect CO_2-eq intensity of the construction sector as well as costs associated with each construction sub-sector (S_1, S_2, S_3, S_4 and S_5) in the bill of quantities for each building, cost associated with materials process CO_2-eq intensities C_p used in the building are used as a deterministic input variables. This is because Monte Carlo analysis has the disadvantage of introducing more errors into an analysis by assuming distributions for input variables without any particular basis (Nawrocki, 2001). To overcome this disadvantage no distributions are assumed for input variables such as I-O sectoral indirect embodied CO_2-eq intensities, which are difficult to estimate. The level of uncertainty in input-output data is difficult to estimate because the national input-output tables are compiled from a wide range of sources such as national systems of accounts, national economic sources, industry sector reports and statistical data, etc. Expenditure is assumed to be constant and hence deterministic.

5.3 Hybrid Embodied CO_2-eq Intensity Distributions of Apartment Building Sector

The $HECO_2$-eq analysis is applied to each of the seven apartment buildings used as case studies using Monte Carlo analysis. Their respective statistical properties and corresponding diagrams are presented in Tables 5.12 to 5.18 and Figures 5.12 to 5.25 respectively. The scatter diagrams among Figures 5.12-5.25 are a plot of the $HECO_2$-eqI of each apartment building and the result or simulation number. That is, each scatter point is a plot of $(x, y) = (HECO_2eqI,\ \text{Results Number})$; where Results Number ranges from 1 to 10,000 Monte Carlo simulations. The scatter plots show the dispersion of the $HECO_2$-eqI Monte Carlo results of each of the apartment buildings due to the uncertainties in input variables. The probability distributions corresponding to the simulated $HECO_2$-eqI of each of the apartment buildings are also presented among

Figures 5.12-5.25. The probability distribution gives an indication of the variation in emission intensities and the likelihood and of obtaining particular $HECO_2$-eqI for an apartment building given the uncertainties in input variables. For each apartment building, the deterministic $HECO_2$-eqI and the mean of the stochastic $HECO_2$-eqI were calculated. The deterministic $HECO_2$-eqI is calculated using average value of the variables using in Equation 3.1. The mean of the stochastic $HECO_2$-eqI is calculated as the average of the 10,000 generated results obtained in the Monte Carlo analysis implemented using Equation 3.1 for each apartment building (Refer to Section 3.2.1). Other statistical parameters which were determined for each distribution are: median and percentage difference, range, inter-quartile range and skewness of the distribution. Each of the distributions was derived from 10,000 simulated results obtained from the hybrid relationship in Equation 3.1. The stochastic $HECO_2$-eqI provides a clear understanding of the probabilities of the distributions and summarized results in the form of charts and graphs with more detailed statistical information compared to deterministic results. Furthermore, stochastic $HECO_2$-eqI analysis using Monte Carlo technique helps to provide information about a range of outcomes such as best- and worst-case embodied CO_2-eq intensity scenarios and the probabilities of their occurrence as well as the probabilities of specified targets. For example, the best- and worst-case scenarios of the $HECO_2$-eqI of each apartment building are illustrated by the front-end and the tail of the $HECO_2$-eqI distributions or the minimum and maximum $HECO_2$-eqI. The stochastic analysis is able to capture extreme scenarios such as the maximum or long tail of the distributions. However, because of its low probabilities, it has little impact on the results. The differences in the ranges of the distributions are because of the random nature of the stochastic embodied CO_2-eq intensities.

5.3.1 $HECO_2$-eqI Distribution of Apartment Building 1

Summary Statistics: 10, 000 Simulation Points

Table 5.12: $HECO_2$-eqI Statistical Parameters of Apartment 1

Central Tendency (Location)			
Deterministic Value: 2,154	*Stochastic Mean*: 2,133	*Percentage Difference:* 0.98%	*Median:* 1,115
Spread			
Maximum: 18,159	*Minimum:* 713	*Range:* 17,445	*Inter-Quartile Range:* 364
Shape			
Skewness: 3.44			

Fig. 5.12: Scatter Plot of 10,000 simulated results of Apartment Building 1

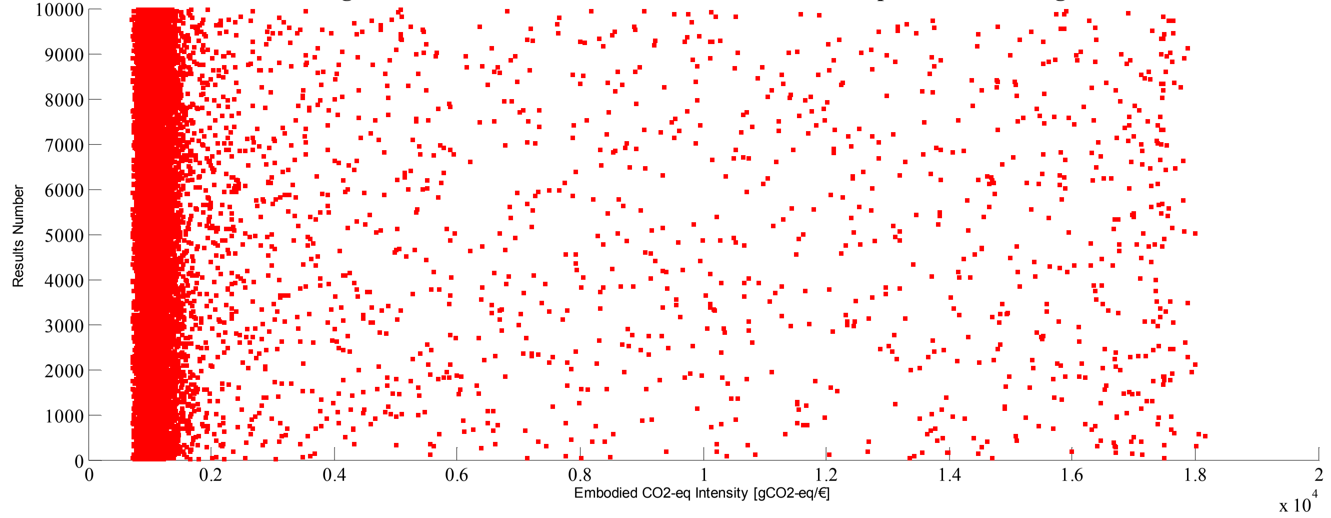
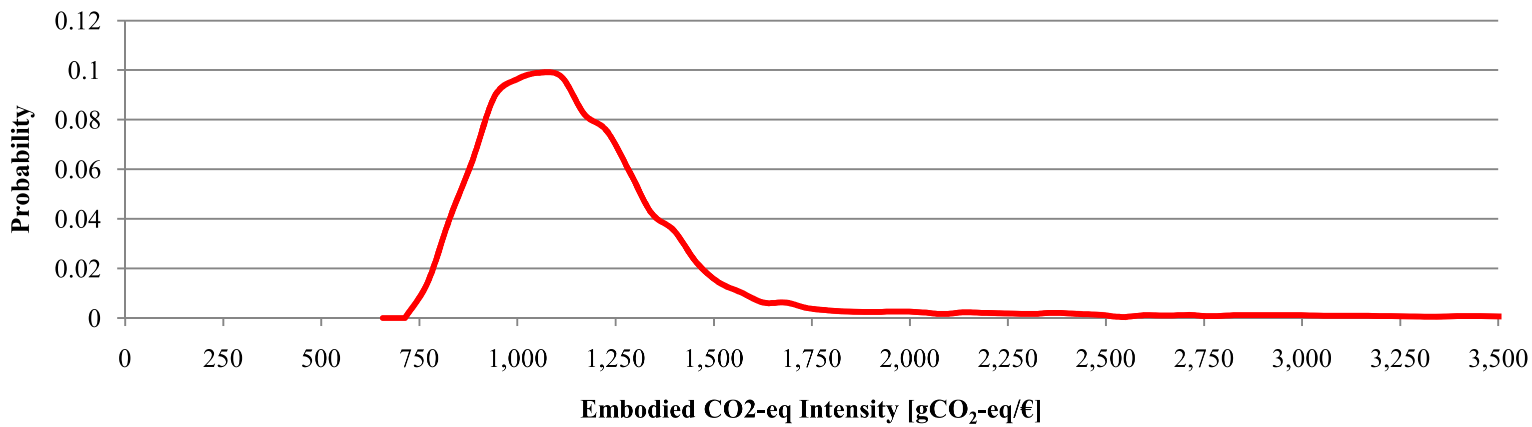


Figure 5.13: $HECO_2$-eqI Distribution of Apartment Building 1



5.3.2 HECO$_2$-eqI Distribution of Apartment Building 2

Summary Statistics: 10, 000 Simulation Points

Table 5.13: HECO$_2$-eqI Statistical Parameters of Apartment 2

Central Tendency (Location)			
Deterministic Value: 1,439	*Stochastic Mean*: 1,354	*Percentage Difference*: 5.9%	*Median*: 1,331
Spread			
Maximum: 57, 806	*Minimum*: 1,325	*Range*: 56, 481	*Inter-Quartile Range*: 133
Shape			
Skewness: 80.5			

Fig. 5.14: Scatter Plot of 10,000 simulated results of Apartment Building 2

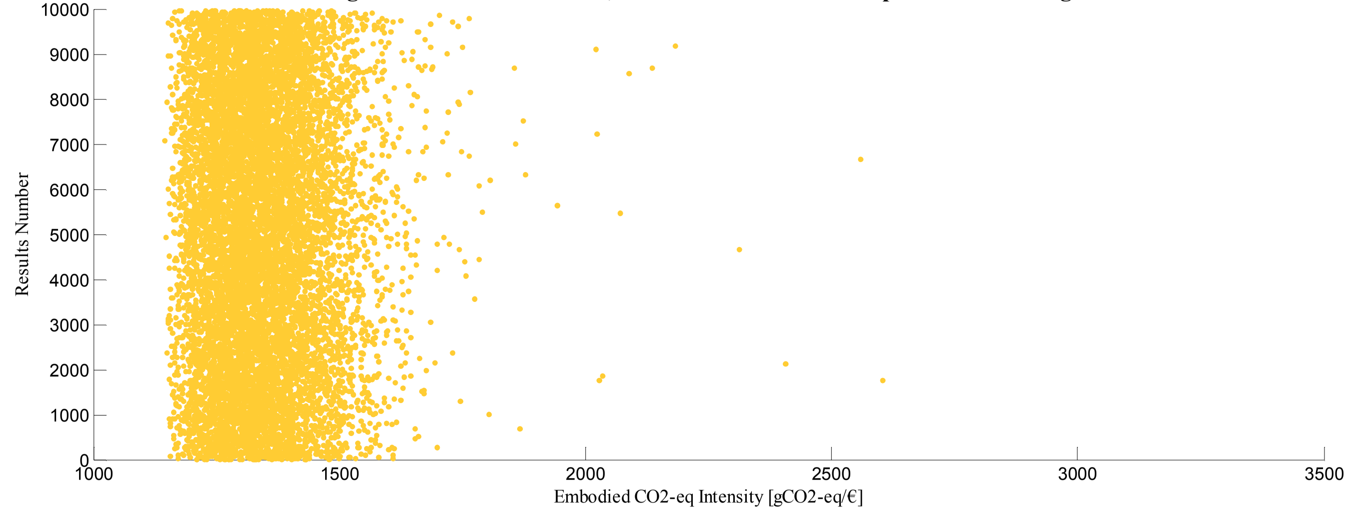
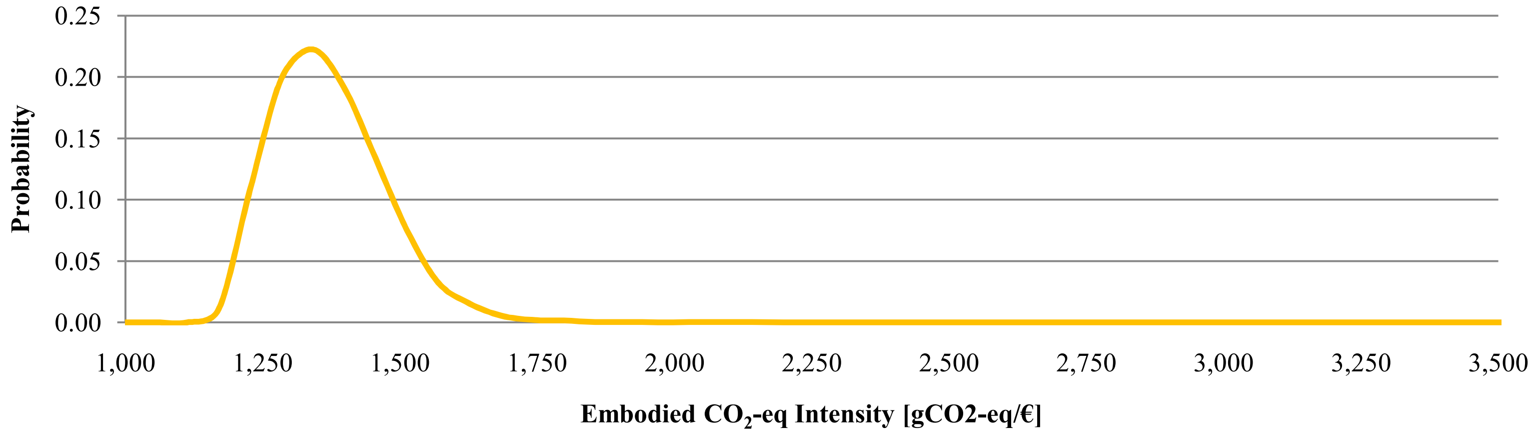


Figure 5.15: $HECO_2$-eqI Distribution of Apartment Building 2



5.3.3 $HECO_2$-eqI Distribution of Apartment Building 3

Summary Statistics: 10, 000 Simulation Points

Table 5.14: $HECO_2$-eqI Statistical Parameters of Apartment 3

Central Tendency (Location)			
Deterministic Value: 1,319	*Stochastic Mean:* 1,284	*Percentage Difference*: 2.6	*Median:* 1,214
Spread			
Maximum: 2,595	*Minimum:* 1,061	*Range:* 1,534	*Inter-Quartile Range:*127
Shape			
Skewness: 3.04			

Fig. 5.16 Scatter Plot of 10,000 simulated results of Apartment Building 3

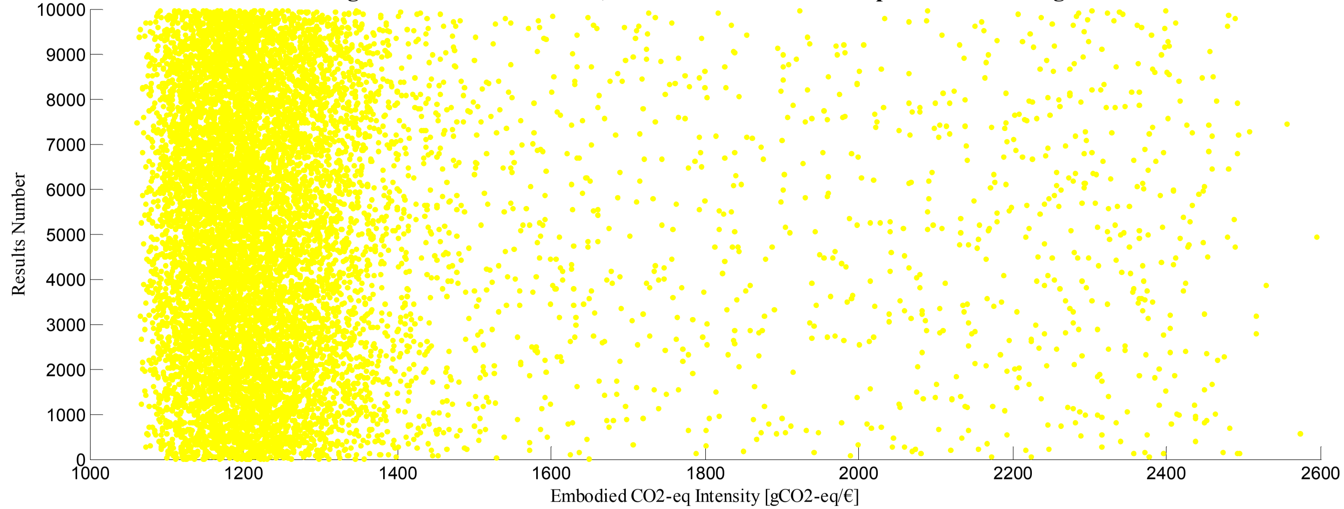
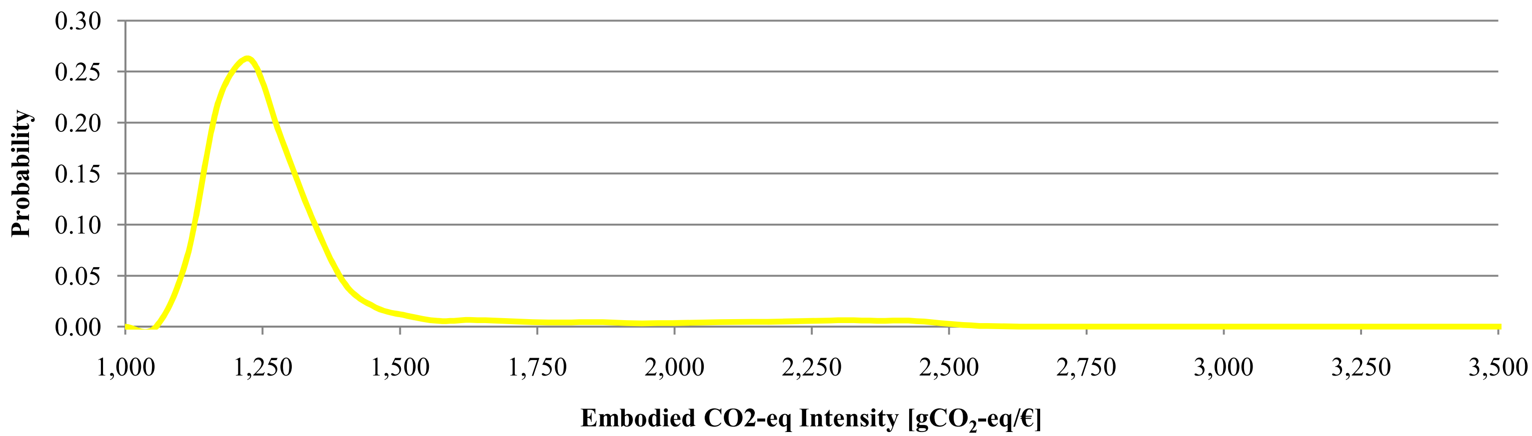


Figure 5.17: $HECO_2$-eqI Distribution of Apartment Building 3



5.3.4 $HECO_2$-eqI Distribution of Apartment Building 4

Summary Statistics: 10, 000 Simulation Points

Table 5.15: $HECO_2$-eqI Statistical Parameters of Apartment 4

Central Tendency (Location): [$gCO_{2\text{-}eq}$/€]			
Deterministic Value: 1,605	*Stochastic Mean:* 1,569	*Percentage Difference*: 2.2%	*Median:* 1,236
Spread: [$gCO_{2\text{-}eq}$/€]			
Maximum: 7,167	*Minimum:* 1,075	*Range:* 6,095	*Inter-Quartile Range:* 131
Shape			
Skewness: 3.59			

Fig. 5.18: Scatter Plot of 10,000 simulated results of Apartment Building 4

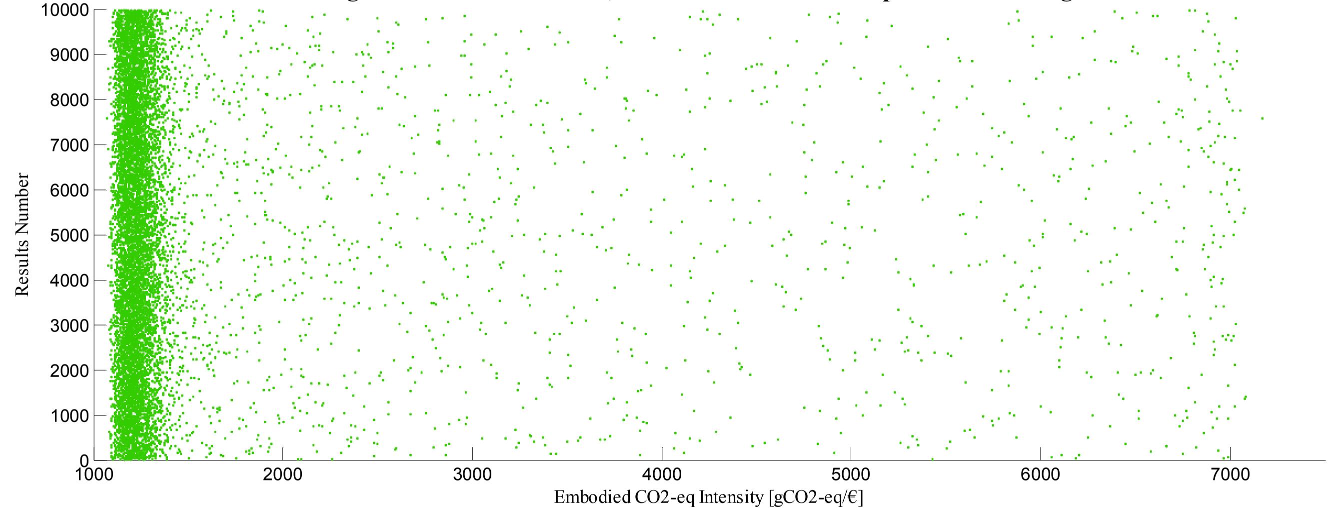
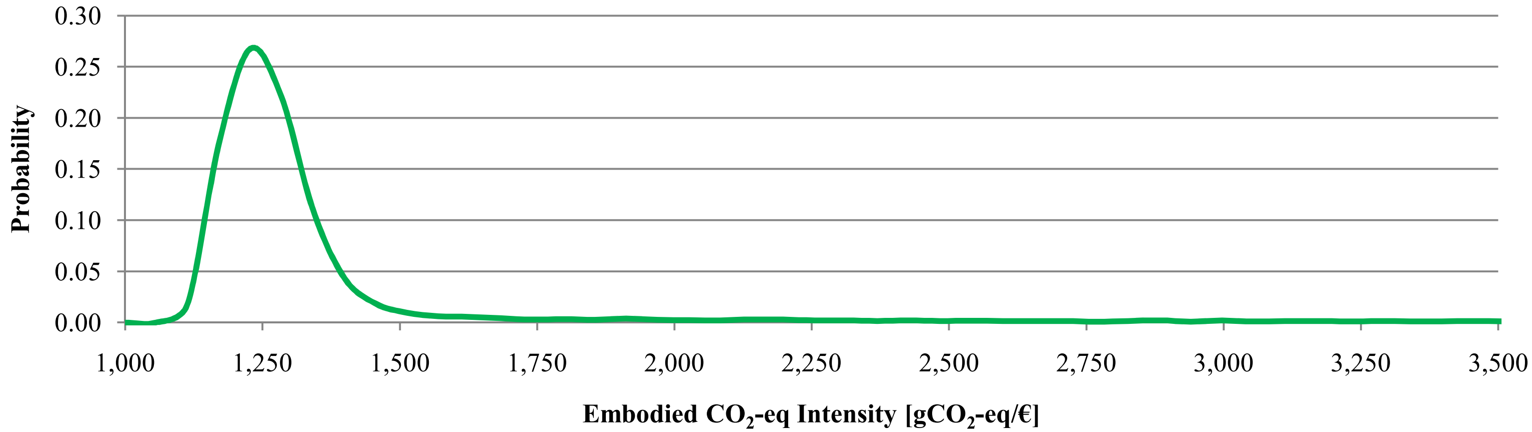


Figure 5.19: HECO$_2$-eqI Distribution of Apartment Building 4



5.3.5 HECO_2-eqI Distribution of Apartment Building 5

Summary Statistics: 10, 000 Simulation Points

Table 5.16: HECO_2-eqI Statistical Parameters of Apartment 5

Central Tendency (Location)			
Deterministic Value: 2,311	*Stochastic Mean:* 2,276	*Percentage Difference*: 1.5%	*Median:* 1,237
Spread			
Maximum: 18,101	*Minimum:* 1213	*Range:* 16,888	*Inter-Quartile Range:* 42
Shape			
Skewness: 3.54			

Fig. 5.20: Scatter Plot of 10,000 simulated results of Apartment Building 5

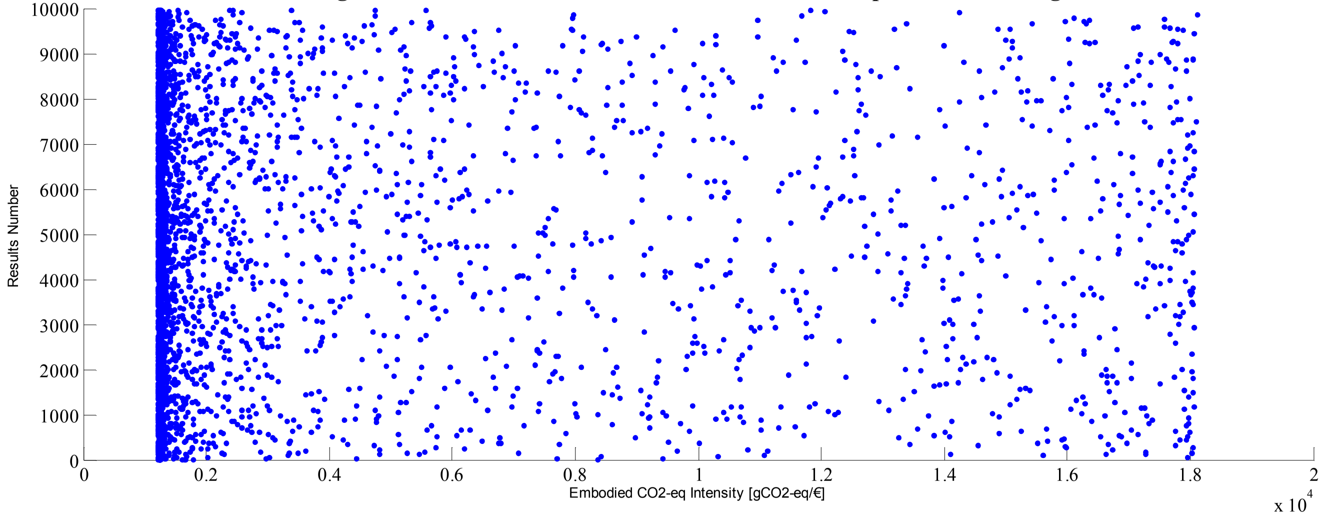
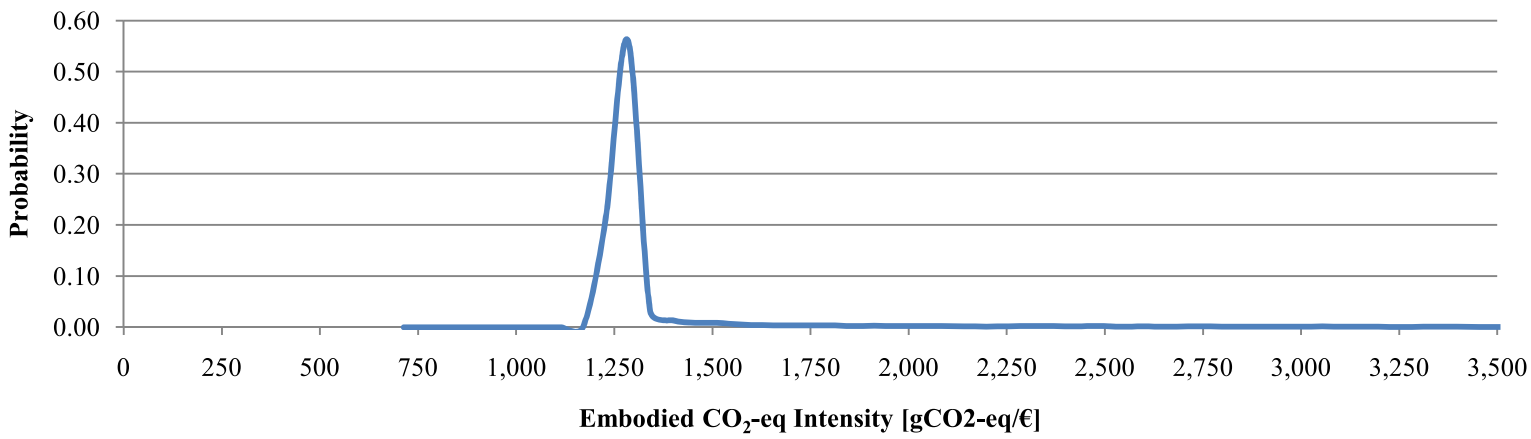


Figure 5.21: $HECO_2$-eqI Distribution of Apartment Building 5



5.3.6 HECO$_2$-eqI Distribution of Apartment Building 6

Summary Statistics: 10, 000 Simulation Points

Table 5.17: HECO$_2$-eqI Statistical Parameters of Apartment 6

Central Tendency (Location)			
Deterministic Value: 1,486	*Stochastic Mean:* 1,455	*Percentage Difference*: 2.1%	*Median:* 1,139
Spread			
Maximum: 6.481	*Minimum:* 1,071	*Range:* 5,410	*Inter-Quartile Range:* 107
Shape			
Skewness: 3.52			

Fig. 5.22: Scatter Plot of 10,000 simulated results of Apartment Building 6

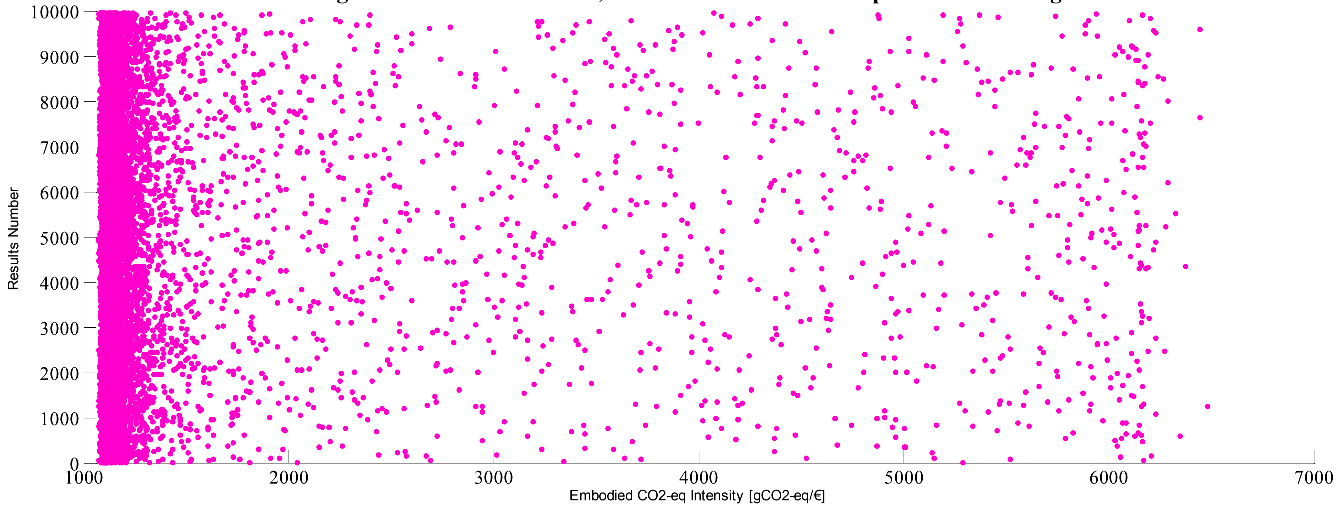
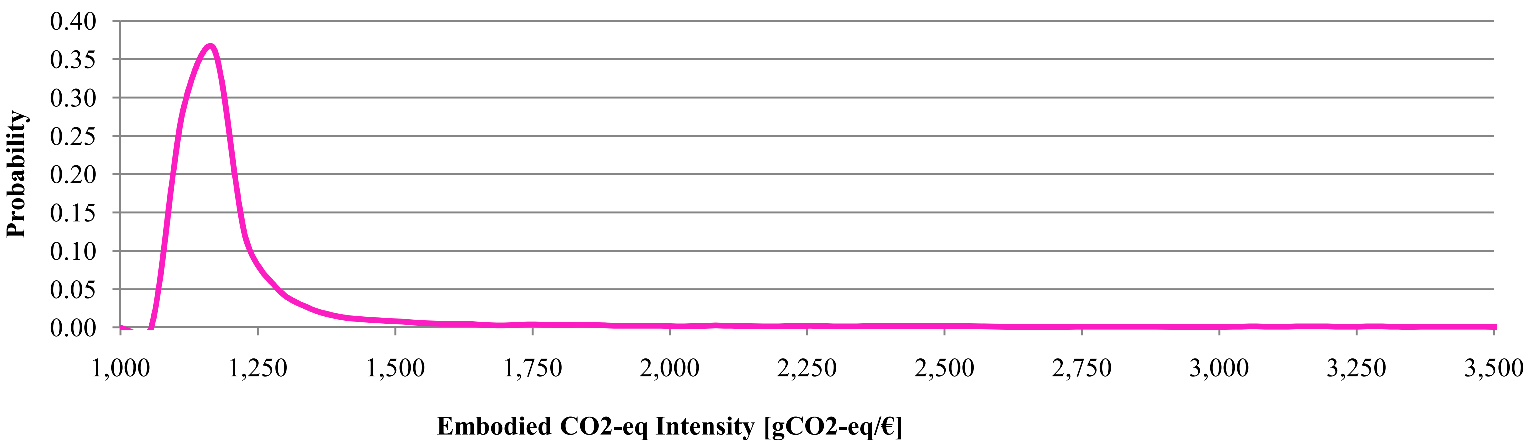


Figure 5.23: HECO2-eqI Distribution of Apartment Building 6



5.3.7 HECO$_2$.eqI Distribution of Apartment Building 7

Summary Statistics: 10, 000 Simulation Points

Table 5.18: HECO$_2$.eqI Statistical Parameters of Apartment 1

Central Tendency (Location)			
Deterministic Value: 1,217	*Stochastic Mean:* 1,162	*Percentage Difference*: 4.5%	*Median:* 1,153
Spread			
Maximum: 1,372	*Minimum:* 1076	*Range:* 297	*Inter-Quartile Range:* 53
Shape			
Skewness: 3.44			

Fig. 5.24: Scatter Plot of 10,000 simulated results of Apartment Building 7

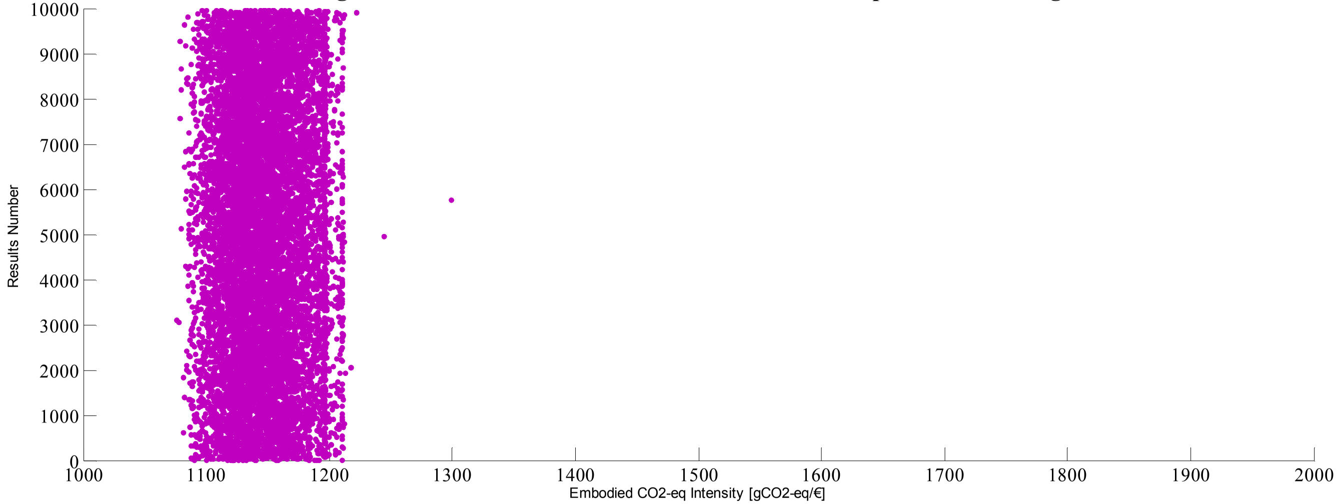
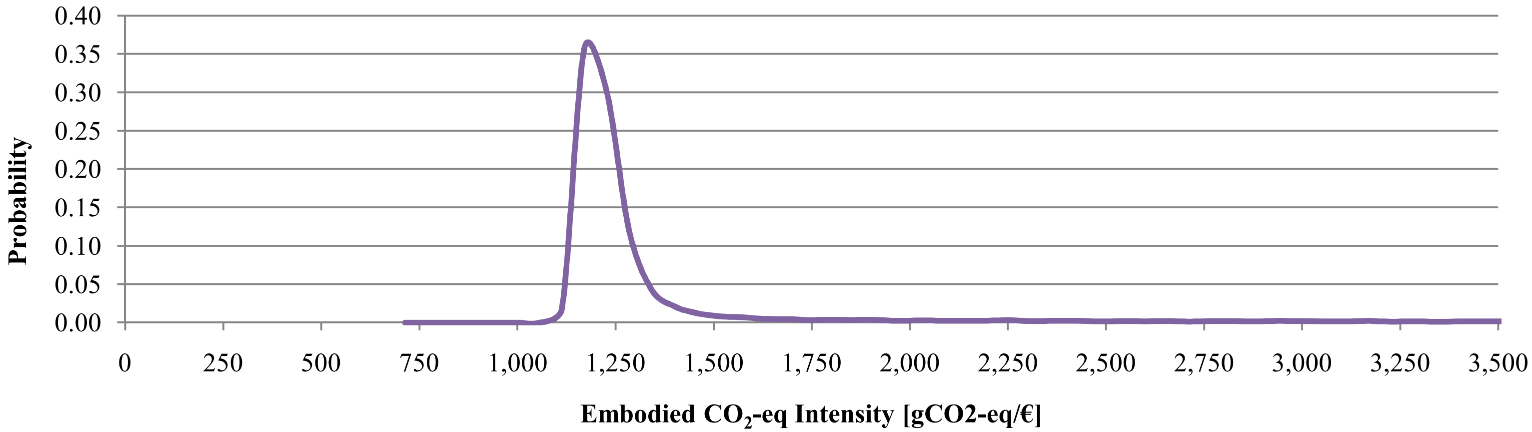
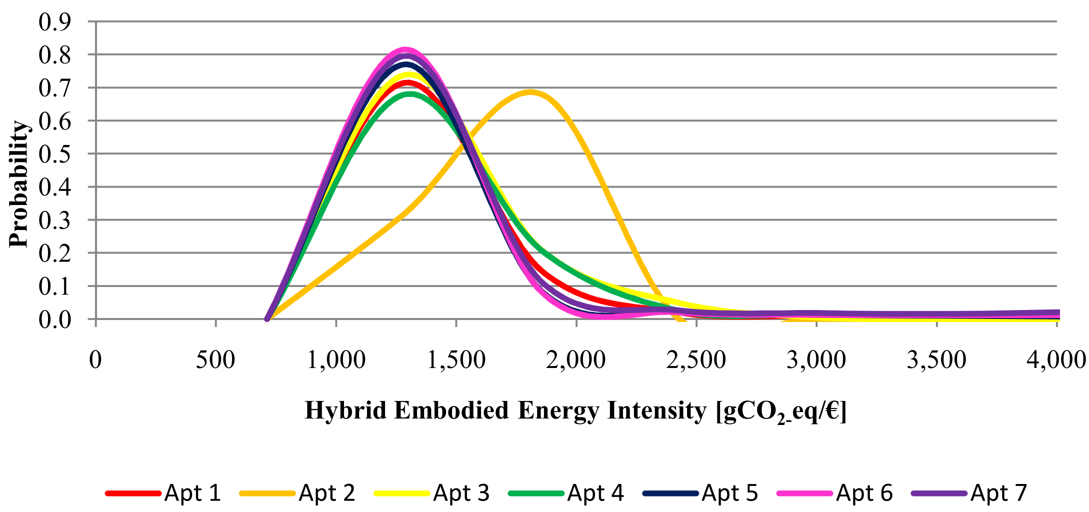


Figure 5.25: HECO$_2$-eqI Distribution of Apartment Building 7



Individual $HECO_2$-eqI distributions for each apartment building are shown in Figure 5.26. All seven of the apartment buildings showed similar distribution characteristics with the exception of Apartment 2 which is more negatively skewed than the others. The differences in this distribution can be attributed to two factors: first, Apartment 2 contained much greater quantities of mechanical and electrical services, the process probability density function for which resulted in negative skewing of the distribution for the overall building; secondly, indirect I-O data displaced a greater proportion of non-services-related process data, thus excluding more positively-skewed distributions from the result.

Figure 5.26: Hybrid Embodied CO_2-eq Intensity Distributions of the Seven Irish Apartment Buildings



The importance of using Monte Carlo technique in the $HECO_2$-eqI is seen in the ability of the model to capture the variability in the $HECO_2$-eqI of each building.

5.4 Derived Embodied CO_2-eq Intensity Probability Distribution of Apartment Buildings in Ireland

The average HECO$_2$-eqI distribution for apartment buildings in Ireland shown in Figure 5.28 can be characterised as a Wakeby distribution with five parameters: $\beta = 1.4 \times 10^2$, $\gamma = 1.3 \times 10^2$ and $\delta = 0.77$ are shape parameters while ζ=0 and $\alpha = 1.5 \times 10^5$ are location parameters. Figure 5.27 is a scatter plot of the embodied emissions intensities of the seven apartment buildings in Ireland from which the average Wakeby distribution was derived. It shows the dispersion of emissions intensities of apartment buildings after 70,000 Monte Carlo simulations due to the variability in input parameters such as emission intensities of building materials.

A general quantile function for a Wakeby Distribution is given by Equation 5.1 below:

Equation 5.1:

$$x(F) = \zeta + \frac{\alpha}{\beta}(1 - (1 - F)^{\beta}) - \frac{\gamma}{\delta}(1 - (1 - F)^{-\delta})$$

Hence, the quantile function describing the derived average distribution for apartment buildings in Ireland is given by Equation 5.2 below:

Equation 5.2:

$$x(F) = 1071(1 - (1 - F)^{1.4 \times 10^2}) - 168(1 - (1 - F)^{-0.77})$$

The distribution was derived using 100 class intervals with a bin or class size of 570gCO$_2$-eq/€. The mean HECO$_2$-eqI was found to be 1,636gCO$_2$-eq/€ while the median was 1,127gCO$_2$-eq/€. This can be interpreted to mean that an 'average' design of Irish apartment buildings built in 2005 will result in the emissions of 1,636gCO$_2$-eq/€. This is based on the assumption that samples are representative of the population of apartment buildings in Ireland.

Using the principle that the uncertainty of a measured result can be taken to represent the estimated standard deviation (US National Institute of Standards and Technology, 1994) the uncertainty associated with the stochastic distribution can be evaluated. It is therefore estimated that the mean of the stochastic distribution of HECO_2-eqI across the apartment building sector is 1,636gCO_2-eq/€ with an uncertainty of 73gCO_2-eq/€. An embodied CO_2-eq intensity of 73gCO_2-eq/€ was estimated as the standard deviation of the Wakeby derived average HECO_2-eqI distribution of apartment buildings in Ireland after 70,000 stochastic simulations. It can therefore be assumed that an embodied CO_2-eq intensity calculated for an apartment building in Ireland would have an uncertainty of 73gCO_2-eq/€. This is approximately 4.5% of the mean (1,636gCO_2-eq/€) of the stochastic distribution. It is however recognized that the addition of stochastic analysis for I-O indirect emissions will change the level of uncertainty in the overall results. This is because Lenzen *et al.* (2000) reported that the estimated inherent errors and variability in I-O data is in the region of 20%. The statistical properties of the distributions of apartment buildings 1-7 showed that the percentage difference between the mean of each stochastic distribution and the deterministic values were respectively 0.98%, 5.9%, 2.6%, 2.2%, 1.5%, 2.1% and 4.5%. Besides apartment 2 (for reasons explained above), these percentage differences are within range of the percentage of the uncertainty of the average distribution to that of the mean of the average distribution.

Obtaining the combined probability distributions of HECO_2-eqI distributions for apartment buildings represents an important step forward if embodied emissions policy measures are to be formulated for this type of dwelling and as an example of the information which could be provided for other types of buildings and infrastructure.

Fig. 5.27: Scatter Plot of 70,000 Monte Carlo simulated results of Embodied Emissions Intensity of Apartment Buildings in Ireland

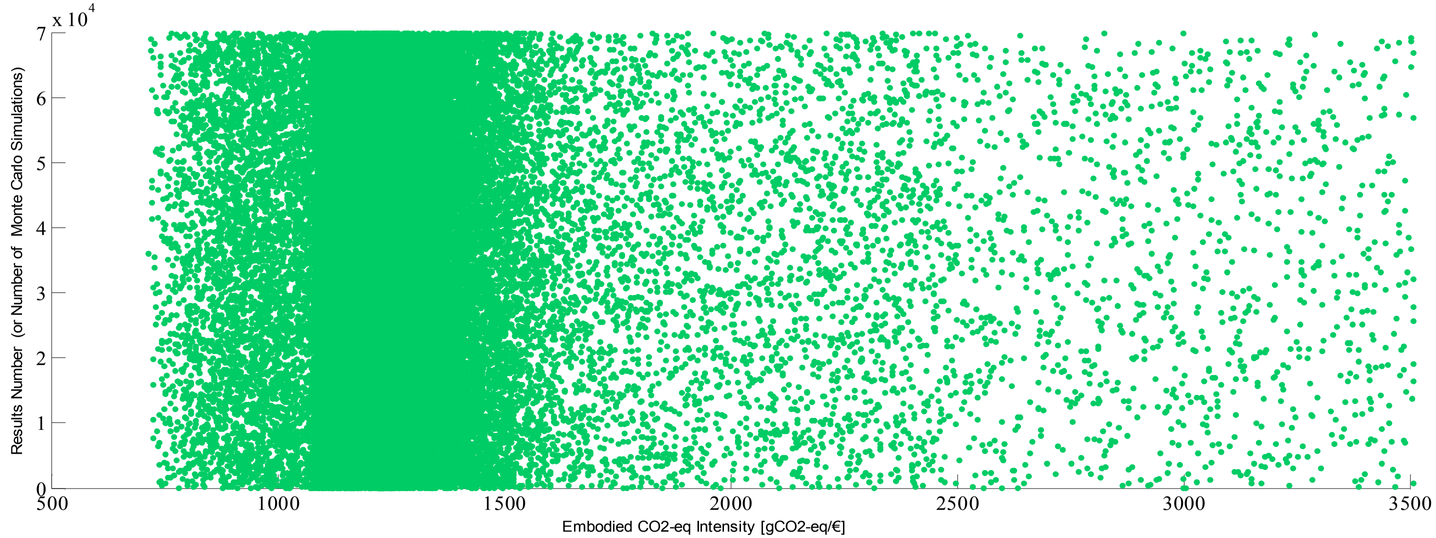
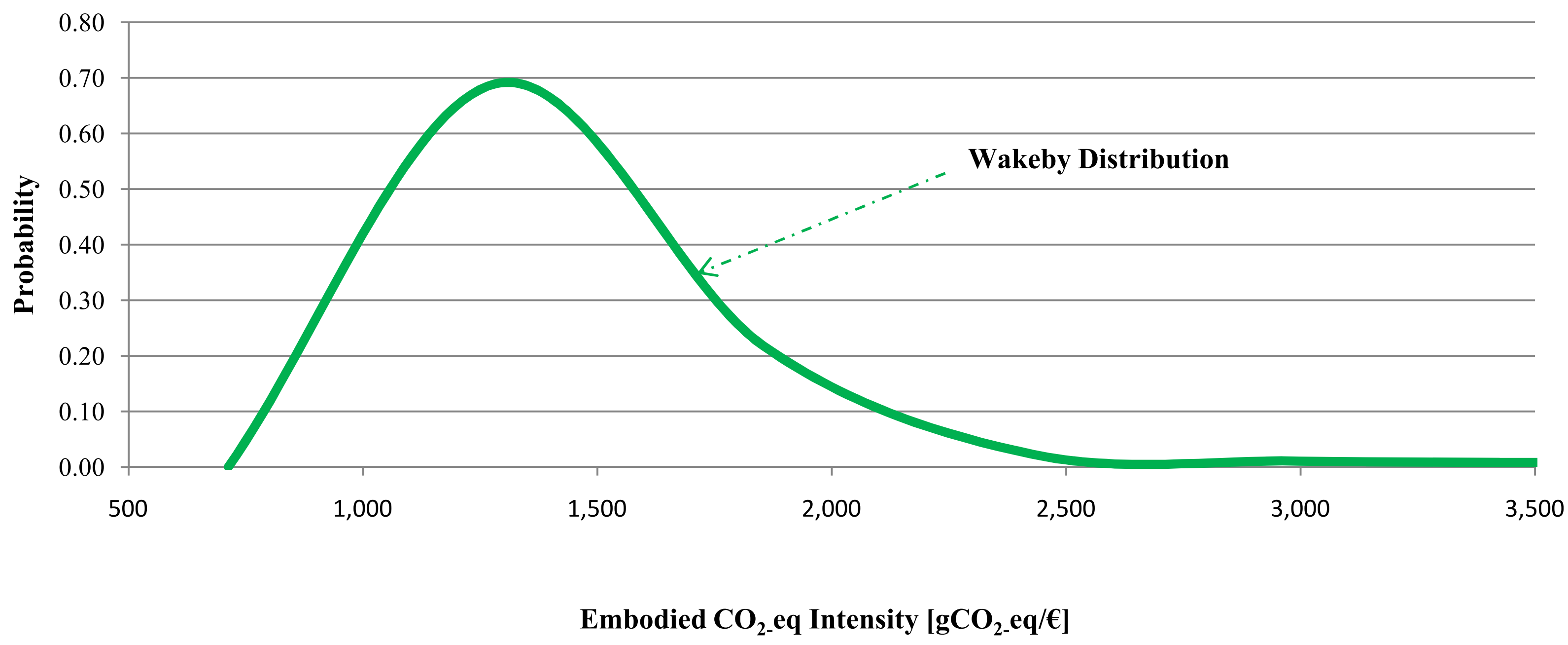


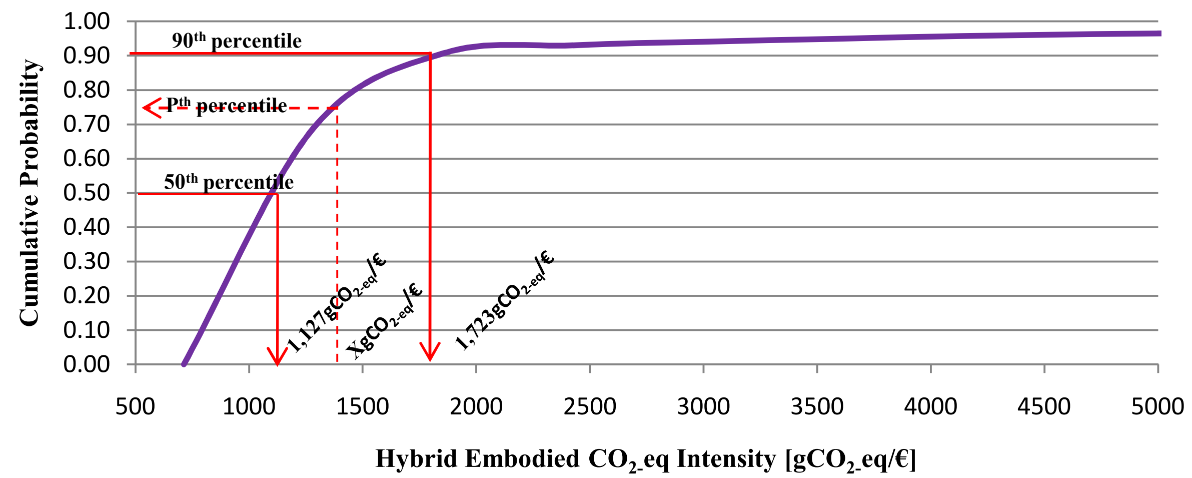
Figure 5.28: Average Embodied CO_2-eq Intensity Probability Distribution of Apartment Buildings in Ireland



5.5 Cumulative $HECO_{2}$-eqI Distribution of Apartment Buildings in Ireland

The cumulative $HECO_{2}$-eqI distribution of apartment buildings in Ireland is presented in Figure 5.29 below.

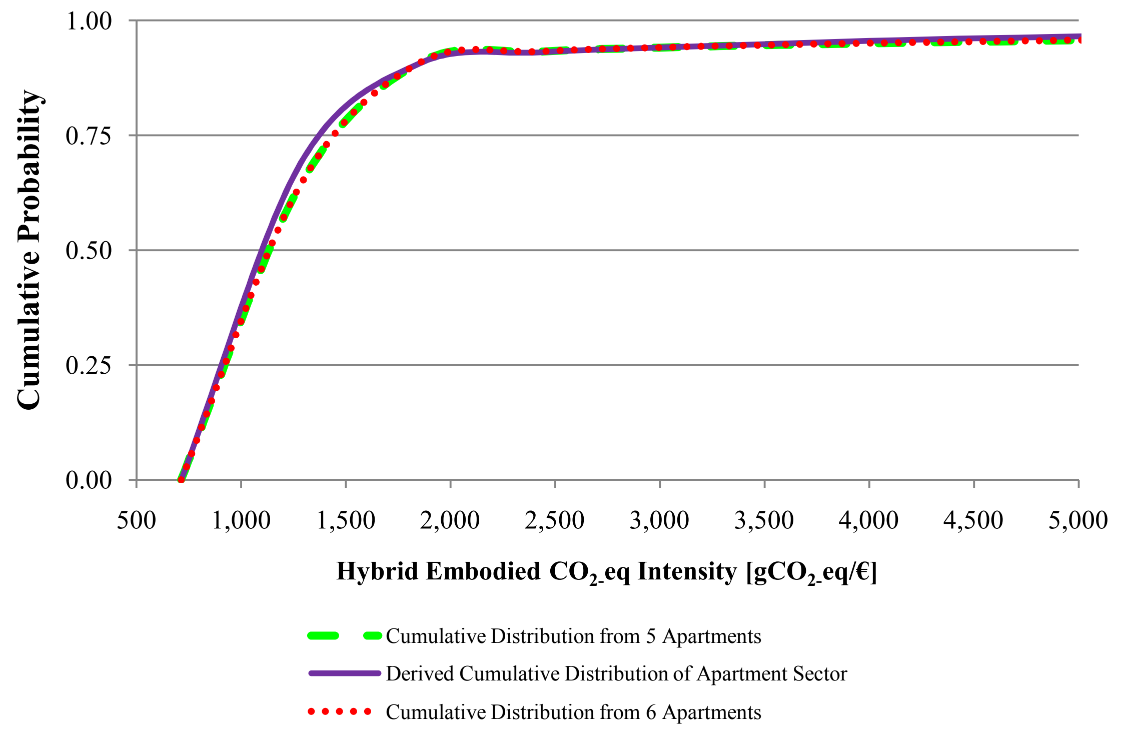
Figure 5.29 : Embodied CO_{2}-eq Intensity Cumulative Probability Distribution of Apartment Buildings in Ireland



The median (50th percentile) and the 90th percentile are respectively 1,127 $gCO_{2\text{-}eq}$/€ and 1,723 gCO_{2}-eq/€ with a stochastic mean of 1,636 gCO_{2}-eq/€. It can be observed that the cumulative probability curve plateaus from a $HECO_{2}$-eqI of 1,723 gCO_{2}-eq/€ indicating that for an embodied CO_{2}-eq intensity greater than this, an apartment building would be in the top 10% of embodied CO_{2}-eq intensities of Irish apartment buildings. If a building designer knows the embodied energy of a building, then the cumulative $HECO_{2}$-eqI probability distribution can be used to determine its performance relative to similar buildings. In the example depicted in Figure 5.29 above, a building with an embodied CO_{2}-eq intensity of XgCO_{2}-eq/€ would correspond to a percentile P meaning its embodied CO_{2}-eq intensity is greater than P% of apartment buildings in Ireland or less than $(100 - P)$% of buildings. This information can be a motivation for a building designer to modify a building design or use less embodied energy materials in order to reduce the embodied CO_{2}-eq of the building.

The cumulative $HECO_{2-}eqI$ distribution is assumed to be representative of the apartment buildings sector in Ireland based on the premise that despite using only seven buildings as case studies, statistical parameters would not significantly change if large numbers of buildings are sampled. To assess the basis of this assumption, a comparison is made between the cumulative $HECO_{2-}eqI$ probability distributions derived from the seven buildings and those derived from a limited number of buildings (5 and 6 apartment buildings represented by Apartment 1-5 and Apartments 1-6 respectively). This is done to determine if there is a significant change in the embodied $CO_{2-}eq$ results due to the use of limited data. The assumption is that, if there is very little difference in the results of these cumulative $HECO_{2-}eqI$ distributions, then neither would there be a significant change even when the distributions are derived using a large number of building case studies.

Figure 5.30 : Comparison of Embodied $CO_{2-}eq$ Intensity Cumulative Distributions



From Figure 5.30, it is found that the 50th percentile (median) and the 90th percentile of the $HECO_{2}$-eqI cumulative probability distribution derived for data from six apartments are 1,233gCO_{2}-eq/€ and 1,722CO_{2}-eq/€ respectively with a mean of 1,678gCO_{2}-eq/€. The 50th percentile (median) and the 90th percentile of the $HECO_{2}$-eqI cumulative probability distribution derived from five apartments are respectively 1,240 gCO_{2}-eq/€ and 1,722gCO_{2}-eq/€ with a mean of 1,723 gCO_{2}-eq/€. Therefore, there are differences of 0.45%, 0.08% and 2.5% between the 50th percentile (median), 90th percentile and mean of the $HECO_{2}$-eqI cumulative probability distributions derived for 6 apartment buildings and those derived for the total sample of seven apartments. Similarly, differences between the 50th percentile (median), 90th percentile and mean of the $HECO_{2}$-eqI derived for 5 apartment buildings and those for the total sample were 1.06%, 0.08% and 5.04% respectively. Because of the marginal percentage differences, it is anticipated that an increase in the sample size is not expected to significantly affect the parameters of the average distribution. Whilst the reasoning behind the sensitivity analysis of $HECO_{2}$-eqI distribution based on the number of cases analysed is valid, statistically a much larger sample size is required to prove this point especially if the distributions are to be used to inform policy making.

5.6 Characterization of Uncertainty in $HECO_{2-}$eqI and Uncertainty Reduction using Bayesian Analysis

International Standard Organization, (1998) stated that:

"Uncertainty is introduced into the results of a Life Cycle Inventory (LCI) due to cumulative effects of input uncertainties and data variability. Uncertainty analysis as applied to LCI is a technique in its infancy. Nevertheless it would help if uncertainty can be characterized to determine uncertainty in LCI results and conclusions. Whenever feasible, such analysis should be performed to better explain and support the LCI conclusions."

Bayesian analysis is applied to probabilistic embodied CO_{2-}eq analysis in order to:

- Provide a systematic basis for updating and reducing uncertainties using new data such as the embodied CO_{2-}eq intensities of building materials and onsite construction energy-use information.

Uncertainties are known to arise from embodied CO_{2-}eq inventory data estimation, old data, incomplete data, model assumptions and aggregation, etc. It is common practice for uncertainty analysis to be excluded from life cycle and embodied energy analysis (Coulon *et al.*, 1997) although the importance of including uncertainty in LCA has long being recognized Ciroth (2004). Maurice *et al.* (2000) and Coulon *et al.* (1997) both suggested that where the quantitative assessment of uncertainty in LCA is not attempted, a qualitative assessment of the reliability of the data should accompany the results of the inventory. The emphasis in the ISO standards on LCA however is on quantitative rather than qualitative uncertainty analysis although it is not a mandatory requirement.

In this section, Bayesian Monte Carlo analysis incorporating Monte Carlo techniques and Bayesian inferences is shown how it can be used as a quantitative assessment method to analyse uncertainties in embodied CO_2-eq intensities of apartment buildings in Ireland. Bayesian Monte Carlo analysis has been employed in studies including uncertainty analysis in ground water-flow (Sohn *et al.,* 2000) and air quality prediction (Bergin *et al.* 2000). With Monte Carlo analysis, uncertainties in the model parameters are represented as probability distributions. However, a lack of data which are required to specify the distribution of some stochastic model parameters (such as I-O sectoral indirect CO_2-eq intensity) is a limitation to this methodology. By combining Monte Carlo Analysis with Bayesian inference, the problem associated with specifying the distribution of model input parameters can be avoided by updating the preliminary estimates (the 'prior distribution' of embodied CO_2-eq intensities) with new or measured data to give a 'posterior distribution'. According to Dilks *et al.* (1992) information on site-specific observed data can be combined with prior information on parameter distributions to improved estimate of a parameter. Dilks *et al.* (1992) further explains that from Bayesian theory the posterior distribution will contain less uncertainty than the sources used in its determination. Therefore, high quality field data combined with little prior knowledge of parameter distributions will result in posterior distributions based primarily on the field data, but improved by whatever prior information was available. If however strong prior information is combined with poorer field data, the posterior distribution will primarily reflect the prior distribution.

Perriman (1995), Owens (1996) and Ross *et al.* (2002) all recognize that lack of site-specific data is a major source of uncertainty in lifecycle, embodied energy and emissions analysis. For this reason, whenever new data becomes available, a Monte Carlo based stochastic HECO_{2}-eqI analysis undertaken using probabilistic embodied CO_{2}-eq distributions and combined with Bayesian Inference provides a systematic basis for characterizing and updating uncertainties in results.

The overall parameter uncertainties for apartment buildings in Ireland were estimated after combining Monte Carlo analysis results of seven apartment buildings based on probability density functions of the input parameters and the HECO_2-eqI relationship. The uncertainty measured as the standard deviation of the distribution is estimated to be 73gCO_{2}-eq/€. The measured uncertainty measured across the HECO_{2}-eqI distribution of the apartment building sector can then be factored into any calculation.

Bayesian analysis is applied to the embodied CO_{2}-eq analysis using Bayes' Theorem. Assuming that new data are collected for construction site energy-use (representing direct sub-sector CO_{2}-eq intensities) and for embodied CO_{2}-eq intensities of building materials in the supply chain (representing process CO_{2}-eq intensities of building materials), then the posterior probability of the embodied CO_{2}-eq intensity of an apartment building can be evaluated from the Theorem using Equation 5.3.

$$P_i(e_i \mid D) = \frac{L(D \mid e_i) \times P_i(e_i)}{\int_{-\infty}^{\infty} L(D \mid e_i) \times P_i(e_i)}$$

Where:

p_i' = Posterior probability of the embodied CO_{2}-eq intensity of an apartment building

e_i = Embodied CO_{2}-eq intensity of an apartment building (output of the model)

D = Newly obtained data

$L(D|e_i)$ = Likelihood of obtaining the new data, D given model output, e_i

$p_i(e_i)$ = Prior probability of the embodied CO_{2}-eq intensity of an apartment building

The denominator in Equation 5.3 is known as the normalizing constant. It is independent of the model and predicts the newly obtained data. Equation 5.3 becomes:

$$p_i^{'}(e_i|D) = k \ L(D|e_i) \times p_i(e_i) \qquad \text{Equation 5.4}$$

Where:

$$k = [\int_{-\infty}^{\infty} L\,(D|e_i) \times p_i(e_i)]^{-1}$$

$p_i^{'}(e_i|D) \equiv$ Posterior (improved) estimate of embodied CO_{2}-eq intensity probability

$L(D|e_i) \equiv$ Likelihood of the parameter value given the obtained data

The statistical parameters of the posterior distribution are calculated from Equation 5.4. If more than one new data point is obtained, the likelihood becomes the product of the likelihood of the individual new data which have been obtained. Equation 5.4 provides an improved probability estimate for the embodied CO_{2}-eq intensity value as a function of the observed data and the prior assessment of the embodied CO_{2}-eq intensity probability. Therefore, the uncertainty reduction in the HECO_2-eqI distribution of apartment buildings in Ireland is realised through the reduction in the uncertainty (measured as standard deviation) between the prior and posterior distributions.

CHAPTER 6:

Building and Construction Sector Emissions Policies

6.0 Overview

Sustainability has become an increasing guiding principle for present and future developments. The Bruntland Commission (World Commission on Environment and Development, 1987) defined sustainable development as:

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

It is well established that the impacts of climate change are major barriers to sustainable development. In the Fourth Assessment Report, the IPCC (2007b) reported that ''climate change could impede nations' abilities to achieve sustainable development pathways''. Energy and emission policies that tackle the causes of climate change have therefore taken up an important role in national and international policy formulations.

It has also been well established that climate change is caused by GHG emissions from all sectors of the economy of which the building and construction sector is a major contributor (Dowden, 2008). The United Nations Environmental Programme, UNEP (2001) for example reported that in 1999, construction activities contributed over 35% of total global CO_2 emissions which was more than any other industrial activity while buildings accounted for more than 40% of total energy consumption. Because of the strong link between GHG emissions, climate change and sustainability and development, GHG emissions policy has now become a central policy of almost all developed economies. Despite the importance of embodied energy and embodied emissions and because it is not directly measured, emissions policies targeted at the building sector have focused historically on promoting operational energy efficiency and the deployment of renewable energy supply (RES) technologies but have failed to directly target embodied CO_{2}-eq of buildings. Given that life cycle assessment can be very important in evidence-based policy making (Duffy 2009) this is a significant omission. Evidence-based policy making however, requires quantitative information. This is problematic since embodied energy and emissions data are not specifically collected by national agencies. Therefore, the data used for estimating the embodied emissions and energy in buildings are typically from multiple sources, often of poor quality and frequently are highly aggregated at an industry sector level. Deterministic approaches therefore yield highly averaged data which may not be very useful to policy makers.

A stochastic application to the embodied CO_2-eq intensity of buildings which generates distributions of buildings and construction-sector emissions intensities are therefore used as quantitative basis for possible emissions policies. Policy options can therefore target the high end of such distribution.

In this chapter, two possible emissions policies derived from the stochastic embodied CO_{2}-eq intensity analysis of buildings and based on its potential to be an effective policy instrument in reducing embodied emissions of buildings in the construction sector are presented. The effectiveness of the emissions policy options are assessed by applying it to the derived embodied CO_{2}-eq intensity distributions for apartment buildings in Ireland.

6.1 Policies Design Targeted at Limiting Embodied Emissions

In this section, policies which can be targeted at embodied emissions in buildings are identified and analysed. The regulation of minimum energy efficiencies and operational emissions is common in the construction sector throughout the world; their extension to cover embodied emissions could therefore be acceptable culturally and be easily integrated into the building procurement process. Two policy options in the areas of regulation and information are investigated using stochastic analysis of $HECO_2$-eqI. The impacts of the policies on input distributions are estimated and re-derived $HECO_2$-eqI output distributions are used to assess their effectiveness.

6.1.1 Policy Option 1: Capping Embodied CO_2-eq Intensity of building materials.

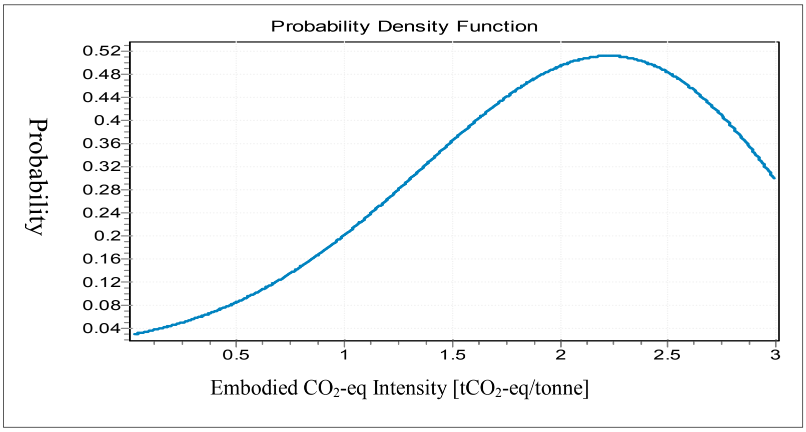
Policy Option 1 is a mandatory certification and labelling instrument which can be classified as a Regulatory-Informative Instrument. It proposes a regulatory intervention in the market by limiting embodied CO_2-eq intensities of building materials to the 80^{th} percentile of the stochastic distributions. The resulting changes in both the $HECO_2$-eqI distribution and embodied CO_2-eq savings are estimated.

6.1.1.1 Application of Policy Option 1 and Test of its Effectiveness

In establishing the quantitative basis for Policy Option 1, $HECO_2$-eqI distribution of apartment building in Ireland derived through Monte Carlo technique is compared to a truncated $HECO_2$-eqI distribution. The truncated distribution was derived by limiting the embodied CO_2-eq intensity of each building material to the 80^{th} percentile of the stochastic distributions for each of the 70, 000 simulation undertaken in the Monte Carlo analysis. Both the change in the $HECO_2$-eqI distribution as well as savings in embodied CO_2-eq emissions was estimated. For example, having derived the cumulative embodied

CO_2-eq distribution of steel, the 80th percentile corresponded to an embodied CO_2-eq intensity of 2.99tCO_2-eq/tonne. Hence the truncated distribution HECO_2-eqI is derived with any input from steel into the stochastic model limited to 2.99tCO_2-eq/tonne representing the 80th percentile of the stochastic distributions. A 20th percentile reduction in embodied CO_2-eq intensity of building materials was randomly chosen but it is in line with other reduction targets set for example by the EU to reduce GHG by 20% and achieve a 20% RES in the energy mix by 2020 (European Commission, 2010). Figures 6.1 and 6.2 demonstrate the capping of the embodied CO_2-eq Intensity of building materials by comparing the original and truncated distribution for steel.

Figure 6.1: Truncated Distribution of Steel: (Generalized Extreme Value Distribution)



[tCO_2-eq/tonne]	Values
Min	0.23
Max	2.99
Mean	2.05
Std. Dev	0.76
Class Int.	0.50

Figure 6.2: Original Distribution of Steel (Refer to 5.1.1.1 for Distribution Parameters)

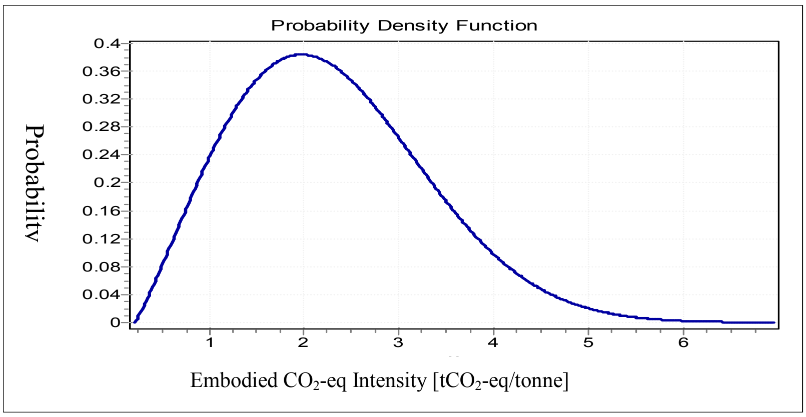


Fig. 6.3: Scatter Plot of Truncated Embodied Emissions Intensities of Apartment Buildings in Ireland

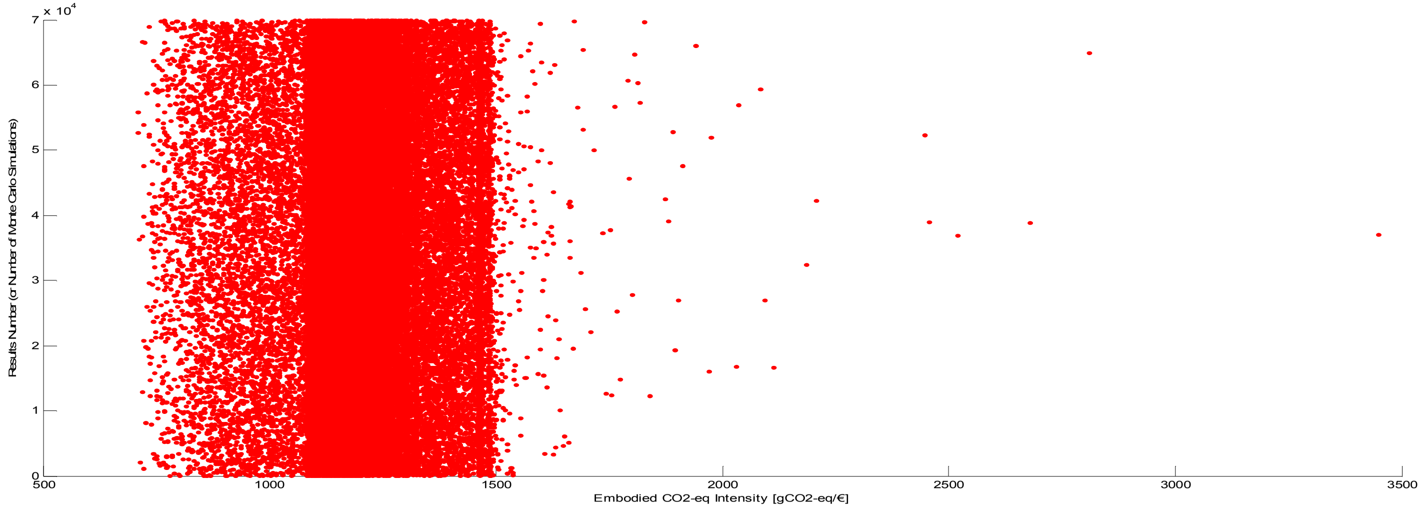


Fig. 6.4: Scatter Plot of Original Embodied Emissions Intensities of Apartment Buildings in Ireland

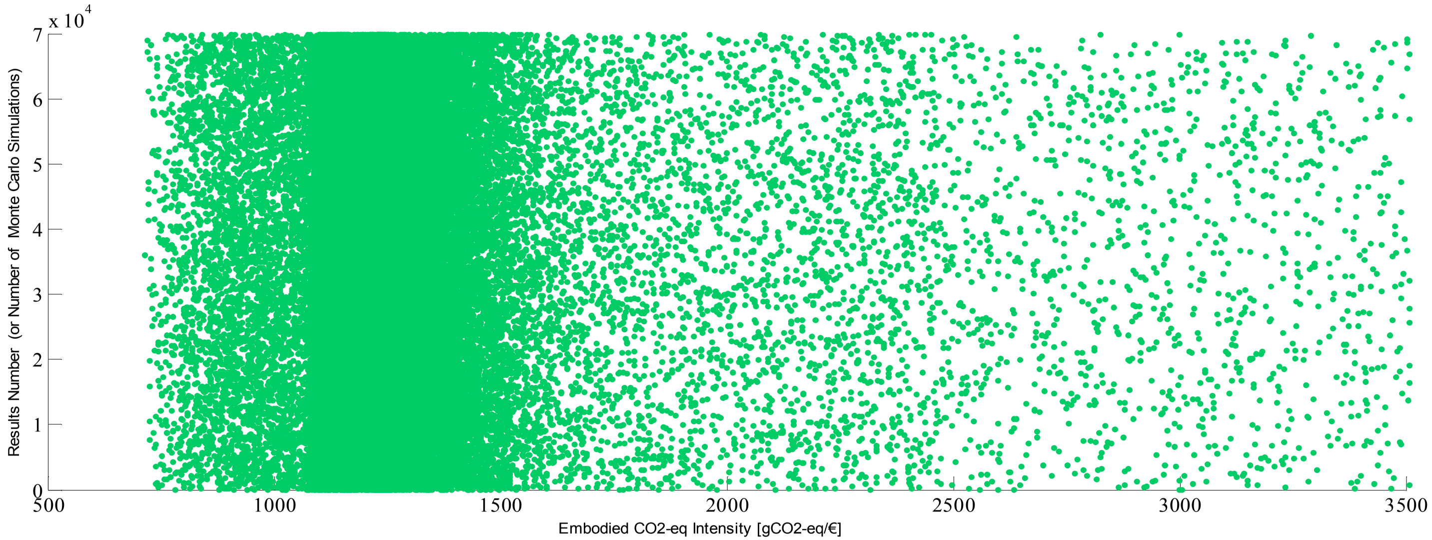
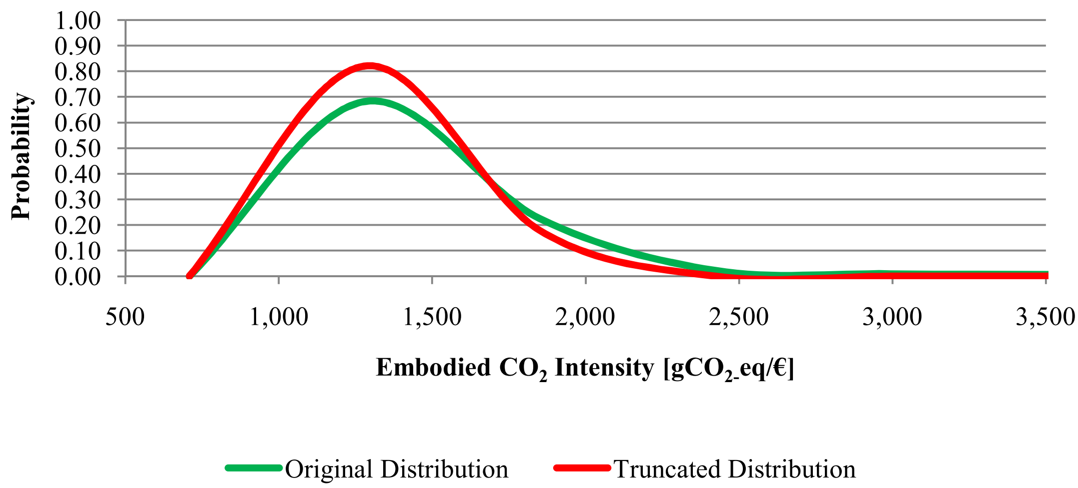


Figure 6.3 shows the scatter diagram of the truncated embodied emissions intensities of apartment buildings in Ireland as a result of implementing Policy Option 1. It can be observed that the highest embodied emissions density of apartment buildings occurs between 1,100 and about 1,350gCO_2.eq/€. On the other hand, the highest embodied emissions intensities density of apartment buildings in Ireland without implementing Policy Option 1 as shown in Figure 6.4 occurs in a much wider range (about 1,100 to about 1,500gCO_2.eq/€). It can also be observed on comparing Figures 6.3 and 6.4 (drawn to the same scale) that generally the number of apartment building with lower embodied emissions intensity is greater in the scatter diagram for the truncated emissions intensities than in the original scatter diagram.

Figure 6.5 also shows a comparison between the original average HECO_2-eqI output distribution for the sample of Irish apartment buildings (described in Section 5.5) as well as the average output distributions using the input distributions of building materials (see Section 5.2.1) which were truncated at the 80th percentile of the stochastic distributions.

Fig. 6.5 Comparison between Original and Truncated Stochastic Embodied CO_2.eq Intensities Distributions



The truncated distribution shown in Figure 6.5 above, have a distribution characteristic described by Cauchy distribution with a general probability density function given by Equation 6.1 below.

Equation 6.1:

$$f(x) = (\pi\sigma(1 + (\frac{x - \mu}{\sigma})^2))^{-1}$$

Where:

σ = continuous scale parameter ($\sigma > 0$)

μ = continuous location parameter

The statistical parameters are given by: σ =53 and μ=1200

Hence, the Cauchy distribution describing the truncated distribution for apartment buildings in Ireland achieved through the implementation of Policy Option 1 is given by Equation 6.2 below:

Equation 6.2:

$$f(x) = (53\pi(1 + (\frac{x - 1200}{53})^2))^{-1}$$

The new mean is 1,186gCO_2-eq/€ compared to 1,636gCO_2-eq/€ for the original distribution. The HECO_2-eqI distribution of apartment buildings in Ireland is therefore transformed from a Wakeby distribution into a Cauchy distribution and reducing the average embodied CO_2-eq intensity by 450gCO_2-eq/€ or 27%. Similarly, the new median is 1,166gCO_2-eq/€ compared to 1,227gCO_2-eq/€ for the original.

The effectiveness of Policy Option 1 is quantified by comparing the original Wakeby $HECO_{2}$-eqI distribution to the truncated Cauchy $HECO_{2}$-eqI distribution. By comparing the two distributions, it is estimated that limiting the $HECO_{2}$-eqI of all buildings materials analysed to 80th percentile of the stochastic distributions results in an average saving of 450gCO_{2}-eq/€ for the sample.

In 2005, the output of the Irish construction sector was estimated to be €32billion, of which residential construction accounted for two-thirds of total output (Central Statistics Office, 2008b). Assuming that the average embodied emissions savings of 450gCO_{2}-eq/€ could be applied to all residential construction in Ireland in that year, it is estimated that an embodied CO_{2}-eq saving of approximately 9.6MtCO_{2}-eq could have been realised for 2005. A similar projection can be made at an EU-27 level to estimate the possible embodied CO_{2}-eq savings. In 2005, the EU-27 construction output was estimated at €1,665bn with new residential construction accounting for about 24.6% or €409.6bn. Assuming that the average $HECO_{2}$-eqI saving of 450gCO_{2}-eq/€ associated with above policy could have been applied to all residential development, it is estimated that 184MtCO_{2}-eq of embodied CO_{2}-eq could have been saved for that year. This represents 3.5% of total EU-27 emissions which were estimated at 5,156.8Mt in 2005 (European Commission, 2008b).

Assuming that the EU-27 would have had to pay for carbon credits equal to or exceeding this saving (that is, all emissions arise within the EU) and taking the cost of a carbon credit equal to that of the UN’s Certified Emission Reductions credit rate of €11.10 per tonne (Bloomberg, 2009), it is estimated that the savings associated with the above policy would have been in the order of €2bn. The costs of implementing such a policy would centre on the cost of information provision (e.g. measuring and communicating the emissions intensities of building materials) and auditing this information. Calculating these costs is beyond the scope of this thesis, although it is worth commenting that much of the information (e.g. energy consumption, production output) and communication channels (product literature, technical support) is already collected and provided by manufacturers in the sector and the marginal cost of emissions-specific information is likely to be low - almost certainly significantly lower than €2bn in savings.

The building and construction industry is very important to the many economies in EU-27. In 2005 for example, the Irish construction industry contributed to 19% of GDP and 23% of GNP (FINFACTS, 2007). In 2007, it had a gross operating rate of 22.8%-the highest in the European construction sector (EUROSTAT, 2010). The economic importance of the construction sector in many economies is also translated into it being one of the major contributors to total national emissions. As such, energy and emissions policy options must be investigated and effective ones based on evidence and scientific information explored to help reduce total energy use and emissions in the sector. The difference in the original and truncated distributions for instance reveals embodied CO_2-eq emissions reductions that can be achieved by limiting embodied CO_2-eq emissions from building materials. The stochastic $HECO_2$-eqI is shown to also provide evidence and quantitative basis for regulation in the building sector targeted at building material producers and the supply chain.

6.1.2 Policy Option 2: Embodied CO_2-eq Rating Scheme and Normalised Comparison of the ECO_2-eq Intensity of Buildings

Policy Option 2 is a Support, Informational and Voluntary Action Policy. This policy involves the provision of normalised embodied emissions information to building designers, developers, local governments, construction firms and others interested parties in order to allow them to rate the impact of a building relative to other similar buildings.

6.1.2.1 Application of Policy Option 2 and Test of its Effectiveness

By illustrating to building designers where in the probability distribution of $HECO_2$-eqI their building lie, they are in a better position to understand how their design compares to others and the potential for reducing embodied emissions through changes in design, material selection or construction practices. Designers will then know the $HECO_2$-eqI of their buildings relative to others and can then work towards driving the embodied CO_2-eq intensity down the lower end of the distribution. For example, the designer of Building 1 shown in Figure 6.6 below, which has an $HECO_2$-eqI of 1,284gCO_2-eq/€ would know that its embodied CO_2-eq intensity is greater than 69% of similar buildings in that sector while the designer of Building 2, which has an $HECO_2$-eqI of 3,620gCO_2-eq/€ would realise that only 5% of similar buildings have higher embodied emissions. Figure 6.6 is a cumulative probability distribution of the $HECO_2$-eqI of Irish apartment buildings which illustrates these relationships. It also shows that the mean $HECO_2$-eqI of 1,636 gCO_2-eq/€ corresponds to the 89th percentile.

A possible $HECO_2$-eqI rating of a building together with a Building Energy Rating certificate which is currently employed would enable possible dwellers of a house make an environmental conscious decision regarding the whole life energy performance of a building. Such a scheme would ultimately improve energy awareness in the property market for both homeowners and developers. This awareness is expected to place somewhat higher value on more energy efficient properties. As such, developers would seek to improve the whole life energy performance of their buildings by improving $HECO_2$.eqI of their buildings at the building design stage so as to enhance their value and sustainability.

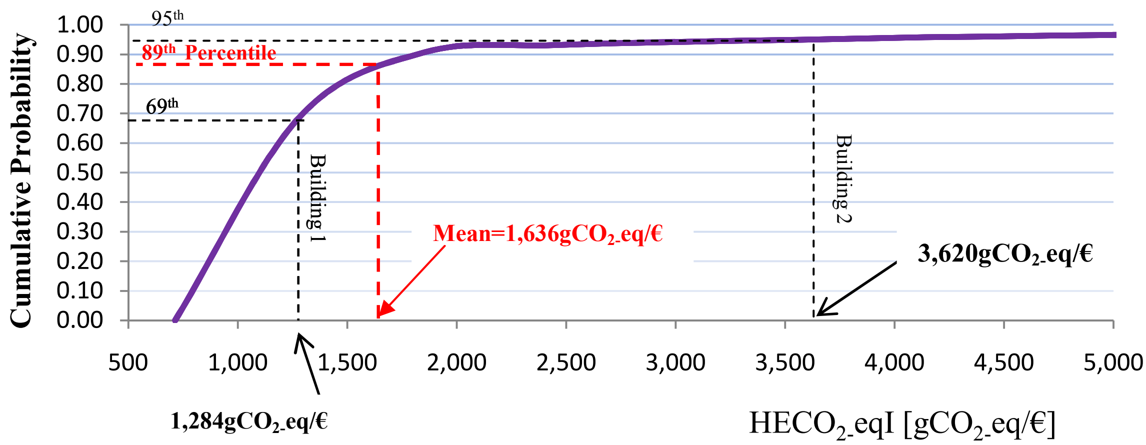
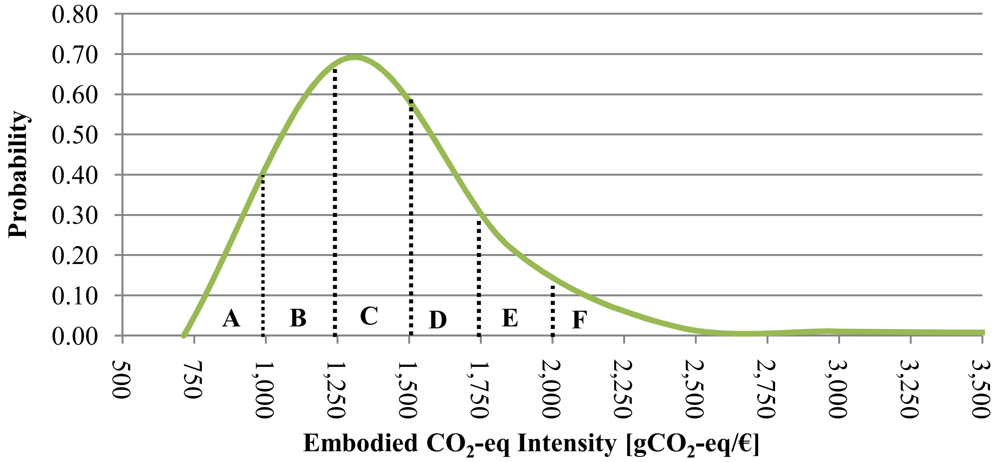


Figure 6.6: $HECO_2$.eqI Cumulative Probability Distribution of Apartment Buildings in Ireland

This informational policy could be extended to give a simple embodied emissions' rating (say A, B, C, D, E, F) to a dwelling - similar to that resulting from the Energy Performance of Buildings Directive - which is obtained from the stochastic $HECO_2$.eqI distributions and updated with data on new dwellings as it becomes available. Through the specification of the $HECO_2$.eqI of building materials on the market, the $HECO_2$.eqI of a building can be calculated and used to rate buildings based on $HECO_2$.eqI matrices such as gCO_2.eq/bedroom, gCO_2.eq/m^2 space or gCO_2.eq/€. An $HECO_2$.eqI rating can be achieved by classifying the combined $HECO_2$.eqI distribution on a scale from low $HECO_2$.eqI to high $HECO_2$.eqI similar to the Certificazione Energetica Degli Edifici in

Italy or the Building Energy Rating scheme employed in Ireland for operational energy use in buildings. For example, the distribution can be banded or classified as Band A to Band F; where Band A represents the lowest embodied CO_2-eq class and Band F the highest embodied CO_2-eq class. For the purposes of the Irish apartment buildings sector depicted in Figure 6.7, classifications might be: Band A<1,000gCO_2-eq/€; 1,000 gCO_2-eq/€ < Band B <1,250gCO_2-eq/€; 1250gCO_2-eq/€ <Band C < 1500gCO_2-eq/€; 1,500 gCO_2-eq/€ < Band D <1,750gCO_2-eq/€; 1,750 gCO_2-eq/€ < Band E <2,000gCO_2-eq/€ and Band F>2000gCO_2-eq/€.

Figure 6.7: Possible Embodied CO2-eq Intensity Rating Scheme



An embodied energy and emissions rating scheme would complement the Building Energy Rating for operational energy use as part of the Energy Performance of Buildings EU Directive. Such an addition would provide a more holistic, life cycle understanding of the energy and emissions performance of buildings. From Figure 6.3, it can be deduced that a minimum of 250gCO_2-eq/€ emissions savings can be achieved, if through embodied CO_2-eq reduction techniques such as design choices, material selection, eco-driving, etc the embodied CO_2-eq rating of the building reduces from Band D to Band B. The classification of a lower embodied CO_2-eq rating for a building would be the main incentive driving this scheme as it has been for similar schemes focussing on operational energy use. The United Nations Environmental Program, UNEP (2007) for example recently reported that mandatory certification and labelling schemes resulted in 3.6MtCO2 emissions savings in Denmark and it is expected that 81MtCO2 would be saved in Australia between 2000 and 2015. Support, informational and voluntary labelling schemes such as the US Energy Star program also resulted in 13.2MtCO_2 emissions savings in 2002 (UNEP, 2007) and it is also expected to result in a cumulative saving of 833MtCO_2 by 2010 (Gillingham *et al*, 2006).

CHAPTER 7

Conclusions and Further Research

7.1 Conclusions

The main aim and objectives of the thesis as set out in Chapter 1 have been addressed. The research aimed to develop a stochastic policy assessment methodology and demonstrate its use taking into consideration data availability and limitations in Ireland and to explore usefulness of uncertainty in evidence based policy making. Specific objectives that were achieved were:

- A review existing embodied energy and CO_2-eq methodologies and data requirements, identify improvements in input-output aggregation and system boundary completeness and calculate the embodied energy and CO_2-eq intensity of Irish construction at a disaggregated level of analysis.
- Development of a stochastic embodied energy and CO_2-eq assessment modelling framework incorporating process and input-output analysis and treatment of uncertainties. This was applied to apartment buildings in Ireland in order to gain an understanding of its embodied CO_2-eq intensity distributions.
- It was investigated how new and relevant data can be incorporated into embodied energy and CO_2-eq emission distributions using Bayesian Updating technique.
- The role that stochastic embodied CO_2-eq assessment can play in evidence based policies were examined and identified policies across the apartment building sector were tested using the stochastic framework.

In Chapter 2, a critical review and analysis of embodied CO_2-eq intensity methodologies was undertake and methodological improvements carried out including:

- IO sectoral disaggregation of the energy supply sectors undertaken using derived disaggregation constants
- Sub-sectoral analysis of Irish construction involving disaggregation and derivation of direct embodied CO_2-eq intensities of the five construction sub-sectors
- System boundary expansion of embodied CO_2-eq framework involving inclusion of imported goods and services,
- Stochastic framework approach to embodied CO_2-eq modelling, its implementation to a building sector and uncertainty estimation,
- Applications of embodied CO_2-eq to evidence-based emissions policy.

These improvements were developed in later chapters. For example, in Chapter 4, the embodied emissions intensity of the Irish construction sector and sub-sectors attributed to national and imports and tier level decomposition of upstream embodied CO_2-eq intensities in Irish construction was calculated. This was achieved by incorporating I-O sectoral disaggregation of the energy supply sectors undertaken using disaggregation constants, system boundary expansion of framework by including imported goods and services in the I-O analysis and sub-sectoral analysis of Irish construction. In Chapter 5, stochastic hybrid embodied CO_2-eq intensity analysis framework employing Monte Carlo technique was developed and applied to apartment building sector in Ireland. This was used to estimate the average embodied CO_2-eq intensity distribution for apartment building in Ireland with known parameters such as mean, median, percentiles and uncertainty measured as the standard deviation of the distribution. The framework in

Chapter 5 was used to illustrate how stochastic analysis can be used as the foundation for evidence-based emissions policies for the building sector as described in Chapter 6.

Many studies have demonstrated the importance of embodied energy and CO_2 analysis in the life cycle assessment of building, emphasising its relative significance when the embodied energy to operational energy ratios are compared-especially for highly operationally efficient buildings. Methodological challenges facing embodied energy and CO_2 intensity assessments have also been highlighted in literature including aggregation constraints such as that of input-output data, the use of average and non-specific process and national data as well as system boundary constraints. The thesis demonstrates how country-specific data of energy used on site were analysed and used to derive direct sub-sectoral CO_2-eq intensities which are then combined with a more generic national input-output data to obtain more construction activity specific intensities.

The study has shown how certain embodied CO_2-eq methodological challenges such as I-O aggregation can be overcome. The three main energy supply sectors of the national input-output sectors include Coal, Peat, Crude and Metal Ore extraction: (NACE 10-13); Petroleum and Other Manufacturing Products: (NACE 23 and 36) and Electricity and Gas: (NACE 40). These were all disaggregated using disaggregation constants derived from the energy balance of Ireland ensuring a threefold advantage. In addition to eliminating non-energy inputs from the analysis it also ensures that specific data –as opposed to average-are applied to the energy supply sectors; such data includes energy tariffs, primary energy factors and emissions intensities. Finally, as shown in the case of the Electricity and Gas sectors, the use of the disaggregation factors avoids the double counting of energy sources such as coal (NACE 10-13) and gas (NACE 40) used in the generation of electricity but also represents a separate energy supply sectors. It is estimated that the indirect energy intensity of Irish construction would be over estimated by more than 2.6 times if the energy supply sectors were not disaggregated and average energy tariffs and emission factors are used.

The analysis of the embodied CO_2-eq intensity of Irish construction sector was also undertaken at a sub-sectoral level. This involved disaggregating the whole construction sector into 5 sub-sectors namely: 'Ground Works', 'Structural Work', 'Services', 'Finishes' and Plant Operation'. The respective sub-sectoral direct embodied CO_2-eq intensities were estimated to be 139 gCO_2-eq/€, 55 gCO_2-eq/€, 31 gCO_2-eq/€, 45 gCO_2-eq/€ and 337 gCO_2-eq/€ with an average of 56 gCO_2-eq/€ which was obtained after weighting each respective sub-sectoral direct embodied CO_2-eq intensities against the output of each sub-sector over four years from 2003-2006. The dominant sub-sector was determined to be Sub-Sector 2 constituting approximately 79% of construction activity in the sector.

For an open economy such as Ireland's the use of the matrix of direct requirement coefficients and Leontief inverse matrix which was derived for domestic product flows in embodied CO_2-eq I-O analysis would represent a significant methodological error since it ignores CO_2 arising abroad as a result of economic activity in Ireland. This is because as Pacca (2003) points out, system boundary can also represent a source of significant uncertainty in an energy assessment framework. By re-deriving the matrix of direct requirement coefficients and Leontief inverse matrix methodological improvements were made by ensuring system completeness. The re-derived I-O table include imported goods and services and therefore avoids system boundary problems. Furthermore, given that energy and emission policies span EU-27 member states, it is important that emissions are treated holistically, given that the EU accounts for 56% of all Irish imports. Data was unavailable for I-O matrix for EU imports; hence the I-O matrix for direct requirement coefficient and Leontief inverse matrix was re-derived using Irish I-O import matrix which includes that for the EU. Of the 1,364gCO_{2}.eq/€ estimated as the total embodied CO_2-eq of Irish construction, 215 gCO_{2}.eq/€ or 16% is estimated to arise from domestic sources comprising 56 gCO_{2}.eq/€ or 4% of direct embodied CO_2-eq intensity and 160 g$CO_{2\text{-eq}}$/€ or 12% arising from domestic indirect emissions. International emissions constituted 1,148 g$CO_{2\text{-eq}}$/€ or 84% of total embodied CO_2-eq intensity emissions.

Given the potential importance of the construction sector to national emissions (UNEP, 2001; Dowden, 2008; Acquaye *et al.,* 2010) CO_2-eq quantifications should not be limited to operational energy use but extended to emissions resulting from energy embodied in buildings. The analysis of direct and indirect embodied CO_2-eq contributions in Ireland indicate that indirect emissions dominate (by 96%: 12% national and 84% international arising) and, policies should prioritise mitigation of indirect emissions.

It is common practice to undertake energy and CO_2-eq analysis deterministically using average data. However, it is widely acknowledged that data variations cause significant uncertainties in calculated results. It has been shown that a stochastic modelling approach to embodied CO_2-eq intensity assessment using Monte Carlo analysis overcomes the limitations of deterministic approaches already highlighted. It is shown that hybrid embodied CO_2-eq intensity mathematical relationship based on process and input-output analysis at a construction sub-sectoral level can be used to achieve such as stochastic analysis. The stochastic hybrid embodied CO_2-eq intensity model is carried out using Monte Carlo technique which simulates embodied CO_2-eq intensity results based on probability distribution characteristics of the embodied CO_2-eq intensities of input variables for building materials and direct sub-sector embodied CO_2-eq intensities.

Monte Carlo sampling undertaken using large number of random values *circa* 10,000 for each input variables captures all possible CO_2-eq intensities embodied in the building. Input distributions were estimated for building materials and energy directly used on site in each of the five sub-sectors. For example, Sub-Sector 2, demonstrated a Log-Logistic distribution characteristic with known probability density function and statistical parameters. This ensured that random input variables into the stochastic hybrid embodied CO_2-eq intensity model could be generated. Likewise, stochastic distributions generated for building materials used in the construction of the apartment building also ensures that variability in process embodied CO_2-eq intensities of building materials was also captured. The outputs of the hybrid stochastic model are embodied CO_2-eq intensities in the form of probability distributions as opposed to discrete numerical values which would have been obtained if a deterministic approach had been taken. Because of the limited availability of data for case studies, seven apartment buildings were used to illustrate the methodology and its policy implications. This represents the first step since the stochastic input distributions can be updated whenever new data and information becomes available. It was determined that the average apartment building in Ireland would have a distribution characteristic described by the Wakeby distribution with the quantile function:

$$x(F) = 1071\left[1 - (1 - F)^{1.4\times10^{2}}\right] - 168\left[1 - (1 - F)^{-0.77}\right]$$

The mean and median were respectively estimated to be 1,636gCO_2.eq/€, and 1,127gCO_2.eq/€. The uncertainty of the distribution- measured by its standard deviation- was estimated to be 73gCO_2.eq/€. Therefore it can be deduced that an 'average' design will result in the emissions of 1,636gCO_2-eq with an uncertainty of 73gCO_2.eq/€. It is however recognized that the addition of stochastic analysis for I-O indirect emissions will change the level of uncertainty in the overall results. This is because Lenzen *et al.* (2000) reported that the estimated error in I-O data is in the region of 20%.

Because of the stochastic nature of the analysis, cumulative distributions were also derived to provide additional analysis and insight into the embodied CO_2.eq intensities of apartment buildings in Ireland. The 5th percentile and the 90th percentile are respectively 1,026 gCO_2.eq/€ and 1,723 gCO_2.eq/€. It was therefore deduced from the HECO_2.eqI cumulative distribution that the top 10% of embodied CO_2.eq intensity of apartment buildings representing the 90th percentile corresponds to the tail of the Wakeby distribution.

Because of the limited number of case studies used in this study, the cumulative distributions of 5, 6 and 7 apartment buildings were compared to determine if their results differed significantly due to differing sample sizes. The hypothesis is that, if the statistical parameters such as the mean, median and 90th percentile of the cumulative distributions do not vary significantly for 5, 6 and 7 apartment buildings then neither would a larger number of apartment building (given the availability of more case studies). It was shown that the percentage difference of the 50th percentile (median), 90th percentile and mean between the average for the apartment building sector (7 apartment buildings) and that of the reduced numbers of buildings were respectively 0.45%, 0.08% and 2.5% (for 6 apartment buildings) and 1.06%, 0.08% and 5.04% (for 5 apartment buildings). It is expected that the general shape of the HECO_2-eqI distribution would not change significantly if a larger number of case studies are used because of the marginal percentage changes in the comparison, although efforts should be made to acquire new data to update the distribution. Whilst the reasoning behind the sensitivity analysis of HECO_2-eqI distribution based on the number of cases analysed is valid, statistically a much larger sample size is required to prove this point especially if the distributions are to be used to inform policy making for the apartment building sector.

Bayesian analysis was identified as a technique that can be applied to embodied CO_2-eq analysis to characterise uncertainty in the HECO_2-eqI distributions given that the distributions may be updated with new information and data. This is based on Baye's theorem. The updating of prior distributions to the posterior distributions provides a systematic basis for updating uncertainties in the stochastically derived probabilistic embodied CO_2-eq distributions.

It is well established that the construction sector is Ireland's and Europe's largest industrial sector contributing significantly to economic growth. However, it is also energy and resource intensive, contributing significantly to total national CO_2-eq emissions. The IPCC (2007a) has recognised that energy and emissions policy instruments represents an important tool that can be used to achieve significant energy saving and emissions reduction in buildings. Duffy (2009) also stated that such instruments should be evidenced-based energy and emissions policies using inputs from life cycle and emission assessments. This reinforces the need for evidence based policy formulation in the built environment.

Broadly-based market-based policies such as the ETS and carbon taxation have already had an impact on embodied emissions. Two further targeted policies were investigated (one regulatory and one informational) based on the potential for emissions reduction in the building sector. These include:

- Policy Option 1: Capping Embodied CO_2-eq intensities of building materials
- Policy Option 2: Informational - Normalised comparison of the Embodied CO_2-eq intensity of buildings and an Embodied CO_2-eq Intensity Rating Scheme of Buildings

The first involves capping the embodied CO_2-eq of building materials at the 80th percentile of their probability distributions. The second provides a normalised comparison of the embodied CO_2-eq intensity of buildings and/or an embodied CO_2-eq intensity rating scheme for buildings. It was observed that capping the embodied CO_2-eq intensity of building materials to the 80^{th} percentile of its stochastic distribution results in the average $HECO_2$-eqI of apartment buildings in Ireland being transformed from a Wakeby distribution into a Cauchy distribution with an average saving of 450gCO_2-eq/€. Assuming that the sample is representative of emissions from residential developments in Ireland and the EU-27, then such a policy would have resulted in savings of approximately 9.6MtCO_2-eq per year (13%) and 184MtCO_2-eq per year (3.5%) respectively if in force in 2005. Assuming that all avoided emissions originated in the EU-27 and assuming a carbon price of €11.10, then it would have had a value of €2bn. Furthermore, the impact of Policy Option 1 can be observed from the probability change in the original and truncated distributions. Policy Option 2 provides designers information about the embodied CO_{2}-eq intensity of their buildings relative to those across the sector using the cumulative embodied CO_{2}-eq intensity distribution derived from the stochastic analysis. Because such information is not currently available and not being used by designers, there is no incentive or competition among designers to design low embodied CO_{2}-eq intensity buildings. It is difficult to estimate the impact of the informational policy, although it is anticipated that it would reduce the variance of the distribution.

Reducing embodied CO_{2}-eq remains an unexploited opportunity in national and international efforts to combat GHG emissions. It is widely accepted that the potential to significantly mitigate CO_2 emissions exists and the necessary tools, support programmes, information and policies must be brought to bear to achieve it. The EU estimates that buildings account for about 40% of EU's energy requirements; if embodied energy is to be included, this value will increase considerably. This thesis shows that use of stochastic techniques to estimate the distributions of embodied CO_{2}-eq intensities in segment of the construction sector can be used to design evidence-based efficient policies. It is estimated that well design targeted policies to mitigate embodied emissions could result in saving 184MtCO_2-eq. This would represent a significant proportion of the 728MtCO_2-eq per year reduction compared to 1990 levels needed to meet the EU-27's 2020 emissions target (European Renewable Energy Council, 2009).

7.2 Further Research

It is hoped that this work can form the basis for further research into stochastic hybrid embodied CO_2-eq assessment of construction and in other economic sectors and a possible inclusion of stochastic analysis of input-output analysis into the framework. With the availability of time, access to large data sets and further methodological advancements, embodied CO_2-eq intensity distributions of many sectors and sub-sectors can be investigated. It is further proposed that combining price elasticity, carbon tax and stochastic analysis be investigated to estimate effects on embodied CO_2-eq intensity distributions.

Given the importance of imported good and services to the Irish economy, research on a Multi-Regional Input-Output analysis of the Irish economy to determine the regional sources of embodied emissions in international trade on economic sectors would be an important step forward in dealing with Irish GHG emissions.

Structural Path Analysis (SPA) has been shown to be a systematic technique that allows for the disentanglement of the intricate network of relationships inherent in a complex system by unfolding the direct requirement coefficient matrix, A (or technology matrix) in input-output analysis into a series of structural paths at the n^{th}order (Lenzen*,* 2007; Lenzen *et al.,* 2009 and Peters *et al.,* 2006). This ensures the unravelling of important structural paths. It is proposed that as a future study to construction sector embodied CO_2-eq assessment, the SPA of construction sector supply chain is investigated with the possible integration into a probabilistic stochastic hybrid embodied CO_2-eq framework to indentify, quantify and rank high emission carbon paths.

Finally, it is recommended that an investigation be carried out to determine how embodied CO_2-eq intensities of buildings can be used to supplement the Building Energy Rating scheme for operational energy use. Further research is needed in bridging the gap between quantitative embodied CO_2-eq assessments and policy formulations. This approach to building sector emissions policy would help to reduce the increasing energy use of the buildings and built environment.

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APPENDICES

Appendix I to VI presents the results of the re-derivation of Matrix of Direct Requirement Coefficients and the Leontief Inverse Matrix which are used in the calculations of embodied CO_2-eq intensities. It also includes intermediate matrices which were derived and provides a source of reference for future work in this area.

APPENDIX I: Input Output Coefficient Matrix corresponding to Imported Products*

	Product	Agriculture, forestry and fishing	Coal, peat, petroleum and metal ore extraction	Other mining and quarrying	Manufacture of food and beverages	Tobacco products
	Product	**1-5**	**10-13**	**14**	**15**	**16**
1 - 5	Agriculture, forestry and fishing	0.0280	0.0000	0.0000	0.0154	0.1149
10 - 13	Coal, peat, petroleum and metal ore extraction	0.0004	0.0905	0.0059	0.0001	0.0000
14	Other mining and quarrying	0.0007	0.0007	0.0316	0.0000	0.0000
15	Manufacture of food and beverages	0.0495	-0.0001	-0.0001	0.0634	0.0000
16	Tobacco products	0.0000	0.0000	0.0000	0.0000	0.0022
17	Textiles	0.0011	0.0000	-0.0001	0.0000	0.0000
18	Wearing apparel	0.0003	0.0005	0.0009	0.0000	0.0000
19	Leather and leather products	0.0001	0.0000	0.0000	0.0000	0.0000
20	Wood and wood products (excl furniture)	0.0001	0.0008	-0.0007	0.0006	0.0031
21	Pulp, paper and paper products	0.0008	0.0000	-0.0037	0.0131	0.0207
22	Printed matter and recorded media	0.0003	-0.0001	-0.0001	-0.0001	0.0000
23&36	Petroleum and other manufacturing products	0.0164	0.0082	0.0438	0.0040	0.0004
24	Chemical products and man-made fibres	0.0614	0.0186	0.0068	0.0007	0.0017
25	Rubber and plastics	0.0010	0.0042	-0.0002	0.0072	0.0001
26	Other non-metallic mineral products	0.0001	0.0009	-0.0019	0.0007	0.0000
27	Basic metals	0.0001	0.0042	-0.0099	0.0019	0.0000
28	Fabricated metal products	0.0055	0.0059	-0.0002	0.0023	0.0010
29	Machinery and equipment n.e.c.	0.0120	0.0179	-0.0033	0.0019	0.0019
30	Office machinery and computers	0.0010	0.0000	0.0001	0.0002	0.0000
31	Electrical machinery and apparatus n.e.c.	0.0001	0.0000	0.0002	0.0000	0.0000
32	Radio, television and communications apparatus	0.0000	0.0000	0.0000	0.0000	0.0000
33	Medical, precision and optical instruments	0.0002	0.0005	0.0004	0.0000	0.0000
34	Motor vehicles and trailers	0.0003	0.0003	-0.0001	0.0000	0.0000
35	Other transport equipment	0.0038	-0.0001	0.0000	0.0000	0.0000
37	Recycling	0.0000	0.0000	0.0000	0.0000	0.0000
40	Electricity and gas	0.0001	0.0004	0.0003	0.0001	0.0000
41	Water collection and distribution	0.0000	0.0000	0.0000	0.0000	0.0000
45	Construction work	0.0000	0.0000	0.0000	0.0000	0.0000
50	Motor fuel and vehicle trade and repair	0.0000	0.0000	0.0000	0.0000	0.0000
51	Wholesale trade	0.0000	-0.0001	-0.0008	0.0308	0.0000
52	Retail trade and repair of household goods	0.0000	0.0000	0.0000	0.0000	0.0000
55	Hotel and restaurant services	0.0000	0.0000	0.0000	0.0000	0.0000
60	Land transport services	0.0000	0.0008	0.0046	0.0003	0.0001
61	Water transport services	0.0001	0.0001	0.0004	0.0000	0.0000
62	Air transport services	0.0001	0.0005	0.0067	0.0008	0.0022
63	Auxiliary transport services and travel agencies	0.0000	0.0000	-0.0001	0.0000	0.0001
64	Post and telecommunication services	0.0000	0.0000	0.0000	0.0000	0.0000
65	Financial intermediation services	0.0000	0.0000	0.0002	0.0018	0.0000
66	Insurance and pension services	0.0000	0.0010	0.0000	0.0008	0.0000
67	Services auxiliary to financial intermediation	0.0000	0.0000	0.0000	0.0000	0.0000
70	Real estate services	0.0000	0.0000	0.0000	0.0000	0.0000

71	Renting services of machinery and equipment	0.0000	-0.0002	0.0003	0.0003	0.0000
72	Computer and related services	0.0000	0.0000	-0.0001	-0.0001	0.0005
73	Research and development services	0.0000	-0.0001	-0.0014	-0.0044	0.0000
74	Other business services	-0.0006	0.0042	-0.0108	0.1572	0.0255
75	Public administration and defence	0.0000	0.0000	0.0000	0.0000	0.0000
80	Education	0.0000	0.0000	0.0000	0.0000	0.0000
85	Health and social work services	0.0000	0.0000	0.0000	0.0000	0.0000
90	Sewage and refuse disposal services	0.0000	0.0000	0.0000	0.0000	0.0000
91	Membership organisation services n.e.c.	0.0000	0.0000	0.0000	0.0000	0.0000
92	Recreation	-0.0002	0.0000	0.0000	0.0000	0.0000
93	Other services	0.0000	0.0001	0.0002	0.0000	0.0000
95	Private households with employed persons	0.0000	0.0000	0.0000	0.0000	0.0000

[1]2005 Use for Imports and Supply Table at Basic Prices can be obtained from Central Statistics Office (2009)

[*]IO Coefficient Matrix $_{\text{Use of Imported Products}}$=Use Table $_{\text{imports}}$ x (Supply Table)$^{-1}$

	Textiles	Wearing apparel	Leather and leather products	Wood and wood products (excl furniture)	Pulp, paper and paper products	Printed matter and recorded media	Petroleum and other manufacturing products	Chemical products and man-made fibres
	17	18	19	20	21	22	23, 36	24
1 - 5	-0.0005	0.0002	0.0005	0.0246	0.0000	0.0000	-0.0001	0.0000
10 - 13	-0.0038	0.0018	-0.0015	-0.0043	-0.0007	0.0000	0.4070	0.0001
14	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
15	0.0005	-0.0002	-0.0001	0.0000	0.0007	-0.0001	0.0000	0.0014
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.2861	0.1239	0.1436	0.0013	0.0016	0.0005	0.0024	0.0001
18	-0.0149	0.2852	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
19	0.0001	-0.0001	0.1579	0.0000	0.0000	0.0000	-0.0001	0.0001
20	-0.0027	0.0010	-0.0003	0.1102	0.0014	0.0001	0.0268	0.0000
21	0.0046	0.0057	0.0050	0.0042	0.2476	0.0114	0.0055	0.0025
22	0.0000	-0.0001	-0.0005	0.0000	0.0020	0.0038	0.0000	0.0001
23&36	0.0052	-0.0015	-0.0018	0.0029	0.0009	-0.0003	0.1104	0.0002
24	0.0890	0.0045	-0.0013	0.0360	0.0369	0.0066	0.0011	0.1119
25	0.0023	-0.0003	-0.0040	0.0029	0.0121	0.0002	0.0070	0.0014
26	0.0003	-0.0002	-0.0002	0.0002	-0.0001	0.0002	0.0055	0.0001
27	-0.0094	0.0027	-0.0004	0.0053	-0.0007	0.0003	-0.0052	0.0002
28	0.0017	0.0035	0.0074	0.0137	0.0033	0.0001	0.0070	0.0005
29	0.0036	0.0011	0.0050	0.0110	0.0032	0.0011	-0.0009	0.0026
30	0.0003	-0.0001	0.0000	0.0000	0.0004	-0.0002	-0.0012	0.0003
31	0.0000	0.0000	0.0000	-0.0002	0.0001	-0.0004	0.0010	0.0000
32	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0005	-0.0001	0.0000
33	0.0000	0.0000	0.0000	0.0000	0.0001	-0.0001	-0.0001	0.0001
34	0.0000	0.0002	-0.0001	0.0000	0.0000	-0.0001	0.0000	0.0000
35	0.0000	0.0004	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000
37	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	0.0002	0.0001	0.0000	0.0003	0.0001	0.0000	0.0001	0.0000
41	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	-0.0011	-0.0001	-0.0020	-0.0002	-0.0018	0.2953	0.0036	0.0041
52	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	0.0003	0.0001	0.0000	0.0006	0.0005	0.0000	0.0001	0.0000
61	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	0.0008	0.0001	0.0001	0.0000	0.0008	0.0011	0.0009	0.0007
63	0.0000	0.0000	-0.0003	0.0000	0.0000	0.0000	0.0000	0.0000
64	0.0000	0.0000	0.0000	0.0000	0.0000	0.0056	0.0000	0.0001
65	0.0001	0.0001	0.0006	0.0000	0.0000	0.0000	0.0006	0.0000
66	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
67	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	0.0002	0.0001	0.0011	0.0001	0.0000	0.0000	0.0000	0.0000
72	0.0000	-0.0001	-0.0003	0.0000	0.0005	-0.0031	0.0003	0.0002
73	-0.0010	0.0002	0.0000	0.0000	-0.0009	0.0723	-0.0007	0.0737
74	-0.0063	-0.0022	0.0126	-0.0012	-0.0040	0.2484	0.0062	0.3533
75	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
91	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
93	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	Rubber and plastics	Other non-metallic mineral products	Basic metals	Fabricated metal products	Machinery and equipment n.e.c.	Office machinery and computers	Electrical machinery and apparatus n.e.c.	Radio, television and communicatio ns apparatus
	25	**26**	**27**	**28**	**29**	**30**	**31**	**32**
1 - 5	-0.0003	-0.0001	0.0000	-0.0002	0.0000	0.0000	0.0000	0.0000
10 - 13	-0.0012	0.0044	0.0839	-0.0038	-0.0001	0.0002	0.0002	-0.0001
14	-0.0001	0.0065	0.0018	-0.0001	0.0000	0.0000	0.0001	0.0000
15	0.0009	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	-0.0001
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	-0.0003	0.0001	0.0000	-0.0001	-0.0002	0.0000	-0.0001	0.0000
18	0.0002	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0002
20	0.0063	0.0015	0.0002	0.0006	0.0001	0.0000	0.0000	0.0004
21	0.0030	0.0085	0.0014	0.0018	0.0014	0.0005	0.0000	0.0022
22	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0001	-0.0004	0.0002
23&36	0.0126	0.0111	0.0509	0.0000	0.0003	-0.0002	0.0020	0.0002
24	0.0557	0.0150	0.0285	0.0047	0.0016	0.0037	0.0038	0.0298
25	0.1436	0.0039	0.0000	0.0040	0.0080	0.0002	0.0047	0.0022
26	0.0041	0.0467	-0.0002	0.0021	0.0009	0.0000	0.0003	0.0004
27	0.0166	0.0211	0.1237	0.2379	0.0789	0.0009	0.0029	0.0013
28	0.0186	0.0074	0.0070	0.0372	0.0671	0.0017	0.0026	0.0047
29	0.0199	0.0130	0.0052	0.0249	0.1213	0.0025	0.0012	0.0201
30	0.0004	0.0000	0.0002	0.0004	-0.0031	0.4329	0.0306	0.0337
31	-0.0037	-0.0004	-0.0013	-0.0016	0.0113	0.0181	0.2412	0.0317
32	-0.0008	-0.0001	-0.0001	-0.0017	0.0015	0.0373	0.0495	0.2388
33	-0.0012	0.0000	0.0000	-0.0001	0.0001	0.0002	-0.0016	0.0091
34	0.0001	0.0002	0.0000	-0.0004	-0.0001	0.0001	-0.0001	0.0000
35	0.0000	0.0000	0.0000	-0.0006	0.0004	0.0001	-0.0002	0.0000
37	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
40	0.0003	0.0004	0.0004	0.0001	0.0001	0.0000	0.0001	0.0001
41	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	-0.0013	-0.0003	-0.0002	-0.0006	0.0008	0.1215	0.0360	0.0423
52	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	0.0005	0.0004	0.0000	0.0002	0.0002	0.0000	-0.0004	0.0000
61	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	0.0009	0.0022	0.0015	0.0007	0.0005	0.0004	0.0021	0.0016
63	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0002	0.0003
64	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004
65	0.0000	0.0001	0.0000	0.0000	0.0001	0.0003	0.0004	0.0000
66	0.0000	0.0000	0.0026	-0.0001	0.0003	0.0000	0.0000	0.0002
67	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	0.0000	0.0001	0.0000	0.0001	0.0001	0.0005	0.0008	0.0000
72	0.0000	-0.0001	0.0001	0.0000	0.0003	-0.0005	-0.0004	0.0002
73	-0.0008	-0.0002	-0.0012	-0.0002	0.0125	0.0017	-0.0026	0.0267
74	-0.0079	-0.0010	-0.0048	-0.0026	0.0536	0.2213	0.1798	0.0093
75	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
91	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
93	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	Medical, precision and optical instruments	Motor vehicles and trailers	Other transport equipment	Recycling	Electricity and gas	Water collection and distribution	Construction work	Motor fuel and vehicle trade and repair
	33	34	35	37	40	41	45	50
1 - 5	-0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000
10 - 13	-0.0126	0.0000	0.0011	0.0000	0.1000	0.0001	0.0000	0.0001
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0019	0.0000
15	-0.0019	0.0000	-0.0002	0.0000	0.0007	0.0014	0.0001	0.0003
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	-0.0015	0.0001	-0.0001	0.0000	-0.0001	0.0000	0.0022	0.0017
18	0.0003	0.0000	-0.0002	0.0000	0.0000	0.0000	0.0006	0.0002
19	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0004	0.0046
20	-0.0008	0.0001	-0.0001	0.0000	-0.0007	0.0001	0.0119	0.0001
21	0.0029	0.0007	-0.0002	0.0012	0.0005	0.0037	0.0011	0.0005
22	0.0000	0.0000	-0.0001	0.0000	0.0004	0.0020	0.0007	0.0004
23&36	-0.0027	0.0008	0.0004	0.0013	0.1098	0.0059	0.0080	0.0084
24	0.0298	0.0055	0.0014	0.0067	0.0014	0.0209	0.0086	0.0013
25	0.0223	0.0153	0.0031	0.0000	0.0000	0.0061	0.0161	0.0061
26	-0.0001	0.0001	-0.0001	0.0000	-0.0001	0.0006	0.0163	0.0004
27	0.0088	0.0758	0.0523	0.3694	0.0003	0.0053	0.0061	0.0003
28	0.0044	0.0132	0.0009	0.0027	0.0037	0.0024	0.0168	0.0015
29	0.0091	0.0087	-0.0019	0.0051	0.0057	0.0387	0.0130	0.0065
30	0.0044	0.0058	0.0003	0.0000	0.0047	0.0034	0.0027	0.0001
31	0.0204	0.0401	0.0466	0.0000	0.0051	0.0001	0.0181	0.0007
32	0.0115	0.1748	0.0006	0.0000	0.0009	0.0027	0.0018	0.0007
33	0.1969	0.0004	0.0097	0.0000	0.0009	0.0058	0.0019	0.0006
34	0.0000	0.0498	-0.0014	0.0000	0.0003	0.0016	0.0010	0.0286
35	0.0000	0.0022	0.2601	0.0000	0.0000	0.0000	0.0010	0.0007
37	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
40	0.0001	0.0001	0.0002	0.0001	0.0027	0.0008	0.0000	0.0001
41	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0462	-0.0002	0.0008	-0.0001	-0.0003	0.0000	0.0000	-0.0001
52	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	-0.0001	0.0001	0.0000	0.0013	-0.0001	0.0001	0.0000	0.0003
61	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0002
62	0.0006	0.0018	0.0010	0.0000	0.0000	0.0000	0.0001	0.0005
63	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0007
64	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
65	0.0000	0.0001	-0.0116	0.0000	0.0001	0.0000	-0.0004	-0.0010
66	0.0009	0.0003	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000
67	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	0.0001	0.0001	-0.0291	0.0000	0.0001	0.0000	-0.0010	-0.0026
72	0.0015	0.0006	-0.0002	0.0000	0.0019	0.0000	0.0000	0.0000
73	0.0077	-0.0004	-0.0004	0.0000	0.0000	0.0000	0.0000	0.0000
74	0.0643	-0.0015	0.0200	-0.0013	0.0106	0.0000	-0.0002	-0.0009
75	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
91	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
93	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	Wholesale trade	Retail trade and repair of household goods	Hotel and restaurant services	Land transport services	Water transport services	Air transport services	Auxiliary transport services and travel agencies	Post and telecommunication services
	51	52	55	60	61	62	63	64
1 - 5	-0.0001	0.0001	0.0029	0.0000	0.0004	0.0000	0.0000	0.0000
10 - 13	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
15	0.0003	0.0055	0.1504	0.0003	0.0023	0.0016	0.0014	0.0010
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0003	0.0023	0.0021	0.0001	0.0001	0.0004	0.0001	0.0003
18	0.0000	0.0001	0.0018	0.0002	0.0000	0.0003	0.0001	0.0004
19	0.0002	0.0008	0.0014	0.0003	0.0000	0.0002	0.0000	0.0002
20	0.0000	0.0002	0.0008	0.0000	0.0001	0.0000	0.0001	0.0003
21	0.0005	0.0011	0.0018	0.0007	0.0000	0.0002	0.0003	0.0003
22	0.0019	0.0003	0.0005	0.0002	0.0001	0.0001	0.0005	0.0003
23&36	0.0052	0.0042	0.0058	0.0458	0.0261	0.0745	0.0077	0.0022
24	0.0004	0.0023	0.0027	0.0005	0.0001	0.0005	0.0008	0.0002
25	0.0015	0.0017	0.0006	0.0054	0.0009	0.0006	0.0013	0.0074
26	0.0004	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001	0.0005
27	0.0001	0.0005	0.0000	0.0013	0.0001	0.0001	0.0001	0.0010
28	0.0001	0.0004	0.0002	0.0010	0.0009	0.0001	0.0002	0.0004
29	0.0003	0.0022	0.0001	0.0016	0.0007	0.0005	0.0003	0.0022
30	0.0000	0.0000	0.0001	0.0003	0.0006	0.0004	0.0001	0.0013
31	0.0002	0.0006	0.0001	0.0033	0.0006	0.0008	0.0003	0.0100
32	0.0002	0.0001	0.0001	0.0006	0.0000	0.0007	0.0007	0.0679
33	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0003	0.0029
34	0.0003	0.0009	0.0004	0.0075	0.0002	0.0003	0.0007	0.0007
35	0.0001	0.0000	0.0004	0.0057	0.0424	0.0341	0.0037	0.0007
37	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	0.0000	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
41	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0073	-0.0001	0.0000	-0.0001	0.0040	0.0022	0.0000	-0.0007
52	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	0.0000	0.0000	0.0000	-0.0005	0.0000	0.0000	0.1948	0.0000
60	0.0029	0.0001	0.0001	0.0004	0.0003	0.0000	0.0005	0.0001
61	0.0001	0.0000	0.0002	0.0000	0.0153	0.0006	0.0006	0.0003
62	0.0001	0.0002	0.0006	-0.0003	0.0006	0.0139	0.1566	0.0016
63	0.0012	0.0005	0.0007	0.0028	0.0064	0.0034	0.0044	0.0004
64	-0.0001	0.0021	0.0000	0.0008	0.0008	0.0004	0.0001	0.0374
65	-0.0020	-0.0002	0.0000	0.0000	0.0000	0.0062	0.0000	0.0001
66	0.0000	0.0000	0.0000	0.0000	0.0003	0.0034	0.0001	0.0000
67	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	-0.0038	-0.0004	0.0000	0.0000	0.0026	0.0437	0.0000	0.0000
72	0.0009	0.0003	0.0000	0.0000	0.0000	0.0006	0.0008	0.0062
73	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0002
74	0.0338	0.0164	-0.0003	0.0005	0.0432	0.0799	-0.0009	-0.0006
75	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
91	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
93	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000
95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	Financial intermediation services 65	Insurance and pension services 66	Services auxiliary to financial intermediation 67	Real estate services 70	Renting services of machinery and equipment 71	Computer and related services 72	Research and development services 73	Other business services 74
1 - 5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000
10 - 13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
15	0.0002	0.0001	0.0006	0.0000	0.0001	0.0008	0.0022	0.0014
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0001	0.0012	0.0002	0.0001	0.0029	0.0004
18	0.0001	0.0000	0.0002	0.0001	0.0003	0.0002	0.0040	0.0005
19	0.0000	0.0000	0.0002	0.0000	0.0001	0.0001	0.0042	0.0007
20	0.0000	0.0000	0.0001	0.0021	0.0001	0.0001	0.0005	0.0002
21	0.0002	0.0002	0.0009	0.0006	0.0004	0.0001	0.0028	0.0019
22	0.0003	0.0002	0.0005	0.0002	0.0001	0.0002	0.0006	0.0015
23&36	0.0003	0.0008	0.0007	0.0007	0.0038	0.0022	0.0045	0.0035
24	0.0000	0.0000	0.0002	0.0006	0.0002	0.0000	0.0082	0.0013
25	0.0002	0.0001	0.0003	0.0011	0.0003	0.0014	0.0021	0.0007
26	0.0000	0.0000	0.0000	0.0018	0.0000	0.0000	0.0000	0.0000
27	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0002	0.0001
28	0.0000	0.0000	0.0002	0.0005	0.0001	0.0002	0.0001	0.0001
29	-0.0003	0.0001	0.0002	0.0005	0.0104	0.0017	0.0020	0.0014
30	0.0001	0.0000	0.0001	0.0020	0.0004	0.0028	0.0029	0.0005
31	0.0000	0.0000	0.0002	0.0002	0.0009	0.0036	0.0014	0.0004
32	0.0000	0.0001	0.0004	0.0002	0.0009	0.0051	0.0030	0.0004
33	0.0000	0.0000	0.0001	0.0000	0.0003	0.0018	0.0012	0.0005
34	-0.0001	0.0001	0.0003	0.0004	0.0050	0.0012	0.0010	0.0010
35	0.0000	0.0000	0.0002	0.0001	0.0005	0.0005	0.0012	0.0006
37	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
41	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0000	0.0000	0.0000	0.0000	0.0000	0.0738	0.0000	0.0005
52	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002	0.0001
61	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
62	0.0005	0.0002	0.0002	0.0001	0.0005	0.0002	0.0010	0.0017
63	0.0001	0.0001	0.0002	0.0001	0.0004	0.0000	0.0004	0.0005
64	0.0003	0.0289	-0.0010	0.0000	0.0000	-0.0003	0.0000	0.0002
65	0.1654	0.0019	-0.0001	0.0000	0.0498	-0.0003	0.0002	-0.0005
66	0.0043	0.4489	0.0638	0.0000	0.0002	-0.0001	0.0005	0.0006
67	0.0059	0.0154	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	0.0027	0.0003	0.0000	0.0000	0.1230	0.0000	0.0000	0.0002
72	0.0047	0.0015	0.0009	0.0000	0.0005	0.0530	0.0000	0.0038
73	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0272	0.0000	0.0041
74	0.0749	0.0171	0.0512	0.0000	0.0255	0.1812	0.0000	0.1515
75	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
91	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
93	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001
95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Public administration and defence	Education	Health and social work services	Sewage and refuse disposal services	Membership organisation services n.e.c.	Recreation	Other services	Private households with employed persons

	75	80	85	90	91	92	93	95
1 - 5	0.0001	0.0006	0.0002	0.0000	0.0002	0.0001	0.0000	0.0000
10 - 13	0.0020	0.0002	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000
14	0.0000	0.0000	0.0000	0.0005	0.0001	0.0000	0.0000	0.0000
15	0.0017	0.0001	0.0014	0.0020	0.0158	0.0036	0.0004	0.0000
16	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	0.0007	-0.0001	0.0016	0.0006	0.0014	0.0007	0.0028	0.0000
18	0.0046	-0.0001	0.0003	0.0019	0.0036	0.0022	0.0071	0.0000
19	0.0001	-0.0001	0.0000	0.0026	0.0028	0.0015	0.0039	0.0000
20	0.0001	0.0006	0.0000	0.0002	0.0007	0.0004	0.0001	0.0000
21	0.0018	0.0062	0.0038	0.0029	0.0014	0.0006	0.0005	0.0000
22	0.0005	0.0017	0.0001	0.0013	0.0009	0.0008	0.0011	0.0000
23&36	0.0079	0.0045	0.0074	0.0054	0.0034	0.0025	0.0057	0.0000
24	0.0053	0.0031	0.0636	0.0334	0.0069	0.0072	0.0180	0.0000
25	0.0019	0.0001	0.0083	0.0075	0.0018	0.0010	0.0021	0.0000
26	0.0007	0.0000	0.0001	0.0035	0.0009	0.0007	0.0002	0.0000
27	0.0003	0.0000	0.0000	0.0013	0.0001	0.0001	0.0001	0.0000
28	0.0013	0.0014	0.0001	0.0019	0.0000	0.0002	0.0001	0.0000
29	0.0012	0.0001	0.0001	0.0025	0.0010	0.0007	0.0024	0.0000
30	0.0024	0.0036	0.0001	0.0033	0.0002	0.0025	0.0003	0.0000
31	0.0001	0.0000	0.0015	0.0014	0.0006	0.0007	0.0012	0.0000
32	0.0004	-0.0001	0.0008	0.0013	0.0014	0.0033	0.0017	0.0000
33	0.0013	0.0033	0.0168	0.0008	0.0009	0.0004	0.0001	0.0000
34	0.0005	0.0000	0.0001	0.0025	0.0004	0.0003	0.0008	0.0000
35	0.0025	0.0000	0.0001	0.0027	0.0013	0.0008	0.0006	0.0000
37	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
40	0.0002	0.0002	0.0000	0.0002	0.0000	0.0001	0.0001	0.0000
41	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
55	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
60	0.0004	0.0001	0.0001	0.0005	0.0001	0.0000	0.0001	0.0000
61	0.0000	0.0000	0.0000	0.0008	0.0001	0.0001	0.0000	0.0000
62	0.0006	0.0015	0.0003	0.0002	0.0008	0.0005	0.0004	0.0000
63	0.0000	0.0000	0.0000	0.0005	0.0004	0.0002	0.0004	0.0000
64	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
65	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
66	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
67	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
70	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
71	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
72	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000
73	0.0000	0.0019	-0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
74	0.0000	0.0000	-0.0007	0.0000	0.0000	0.0074	0.0000	0.0000
75	0.0027	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
80	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
85	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
90	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
91	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
92	0.0000	0.0000	0.0000	0.0000	0.0000	0.0397	0.0000	0.0000
93	0.0000	0.0001	0.0000	0.0004	0.0002	0.0001	0.0012	0.0000
95	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

APPENDIX II: 2005 Supply Transformation Matrix

	Product	1-5	10-13	14	15	16
1 - 5	Agriculture, forestry and fishing	-	-	-	-	-
10 - 13	Coal, peat, petroleum and metal ore extraction	-	15	-	-	-
14	Other mining and quarrying	-	-	164	-	-
15	Manufacture of food and beverages	-	-	- 1	308	-
16	Tobacco products	-	-	-	-	-
17	Textiles	-	-	-	- 0	-
18	Wearing apparel	-	-	-	-	-
19	Leather and leather products	-	-	-	-	-
20	Wood and wood products (excl furniture)	-	-	-	-	-
21	Pulp, paper and paper products	-	-	-	- 0	-
22	Printed matter and recorded media	-	-	-	-	-
23&36	Petroleum and other manufacturing products	-	-	-	- 1	-
24	Chemical products and man-made fibres	-	-	- 12	- 1,474	-
25	Rubber and plastics	-	-	-	- 1	-
26	Other non-metallic mineral products	-	-	- 288	-	-
27	Basic metals	-	-	-	- 1	-
28	Fabricated metal products	-	-	-	-	-
29	Machinery and equipment n.e.c.	-	-	-	-	-
30	Office machinery and computers	-	-	-	-	-
31	Electrical machinery and apparatus n.e.c.	-	-	-	-	-
32	Radio, television and communications apparatus	-	-	-	-	-
33	Medical, precision and optical instruments	-	-	-	-	-
34	Motor vehicles and trailers	-	-	-	-	-
35	Other transport equipment	-	-	-	-	-
37	Recycling	-	-	-	-	-
40	Electricity and gas	-	-	-	-	-
41	Water collection and distribution	-	-	-	-	-
45	Construction work	-	-	-	-	-
50	Motor fuel and vehicle trade and repair	-	-	-	-	-
51	Wholesale trade	-	- 5	- 67	- 753	-
52	Retail trade and repair of household goods	-	-	-	-	-
55	Hotel and restaurant services	- 31	-	-	-	-
60	Land transport services	-	- 7	-	-	-
61	Water transport services	-	-	-	-	-
62	Air transport services	-	-	-	-	-
63	Auxiliary transport services and travel agencies	-	-	-	-	-
64	Post and telecommunication services	-	-	-	-	-
65	Financial intermediation services	-	-	-	- 2	-
66	Insurance and pension services	-	-	-	-	-
67	Services auxiliary to financial intermediation	-	-	-	-	-
70	Real estate services	- 35	-	-	-	-
71	Renting services of machinery and equipment	-	- 1	- 0	- 5	-
72	Computer and related services	-	-	-	-	-
73	Research and development services	-	- 2	- 0	- 14	-
74	Other business services	- 27	- 20	- 1	- 267	-
75	Public administration and defence	-	-	-	-	-
80	Education	-	-	-	-	-
85	Health and social work services	-	-	-	-	-
90	Sewage and refuse disposal services	-	-	-	-	-
91	Membership organisation services n.e.c.	-	-	-	-	-
92	Recreation	- 40	-	-	-	-
93	Other services	- 30	-	-	-	-
95	Private households with employed persons	-	-	-	-	-

		Textiles		Wearing apparel		Leather and leather products		Wood products (excl furnitur e)		Pulp, paper and paper products		Printed matter and recorde d media		m and other manufac turing products		products and man-made fibres
		17		18		19		20		21		22		23, 36		24
1 - 5		-		-		-		-		-		-		-		-
10 - 13		-		-		-		-		-		-		-	-	1
14		-		-		-		-		-		-	-	0		-
15		-		-		-		-		-		-		-	-	45
16		-		-		-		-		-		-		-		-
17		381	-	61		-	-	0		-	-	1	-	6	-	18
18	-	13		14		-		-		-		-		-		-
19		-	-	0		1		-		-		-	-	1		-
20	-	7		-		-		57	-	1	-	0	-	11	-	1
21	-	1		-		-	-	7		64	-	4	-	0	-	2
22	-	1		-		-		-	-	3		566	-	10	-	20
23&36	-	0	-	1	-	0	-	12	-	0	-	0		309	-	0
24	-	3		-		-	-	0	-	4	-	0	-	14		1,904
25	-	2	-	2	-	1	-	6	-	5	-	1	-	13	-	31
26	-	0		-		-		-	-	0		-	-	4	-	0
27	-	11		-		-		-	-	5		-	-	1		-
28	-	4		-		-	-	9	-	0	-	1	-	132	-	1
29		-		-		-		-	-	1		-	-	15	-	16
30		-		-		-		-		-	-	34	-	8	-	6
31	-	0		-		-	-	1		-	-	9	-	1	-	1
32		-		-		-		-		-	-	1		-	-	0
33	-	0	-	0		-	-	0		-	-	0	-	2	-	32
34		-		-		-		-		-		-	-	0		-
35		-		-		-		-		-		-		-		-
37		-		-		-		-		-		-		-		-
40		-		-		-		-		-		-		-		-
41		-		-		-		-		-		-		-		-
45		-		-		-		-		-		-		-		-
50		-		-		-		-		-		-		-		-
51	-	12	-	12	-	8	-	27	-	6	-	382	-	24	-	202
52		-		-		-		-		-		-		-		-
55		-		-		-		-		-		-		-		-
60		-		-		-		-		-		-		-		-
61		-		-		-		-		-		-		-		-
62		-		-		-		-		-		-		-		-
63		-		-		-		-		-		-		-		-
64		-		-		-		-		-		-		-		-
65		-		-		-		-		-		-		-		-
66		-		-		-		-		-		-		-		-
67		-		-		-		-		-		-		-		-
70		-		-		-		-		-		-		-		-
71	-	0	-	0		-	-	0	-	0	-	16	-	0	-	5
72		-		-		-		-		-	-	691		-		-
73	-	0	-	0		-	-	0	-	0	-	47	-	0	-	15
74	-	0	-	4		-	-	1	-	0	-	435	-	2	-	237
75		-		-		-		-		-		-		-		-
80		-		-		-		-		-		-		-		-
85		-		-		-		-		-		-		-		-
90		-		-		-		-		-		-		-		-
91		-		-		-		-		-		-		-		-
92		-		-		-		-		-		-		-		-
93		-		-		-		-		-		-		-		-
95		-		-		-		-		-		-		-		-

		Rubber and plastics		Other non-metallic mineral products		Basic metals		Fabricated metal products		Machinery and equipment n.e.c.		Office machinery and computers		al machinery and apparatus n.e.c.		communication s apparatus s
		25		26		27		28		29		30		31		32
1 - 5		-		-		-		-		-		-		-		-
10 - 13		-		-	-	14		-		-		-		-		-
14	-	6	-	157	-	0		-		-		-		-		-
15		-		-		-		-		-		-		-	-	7
16		-		-		-		-		-		-		-		-
17	-	3	-	3		-	-	1	-	1		-		-		-
18		-		-		-		-		-		-	-	0	-	0
19	-	0	-	0		-		-		-		-		-		-
20	-	17	-	5		-	-	14		-	-	0		-		-
21	-	3	-	0		-	-	1		-	-	44		-		-
22	-	1		-		-	-	1		-	-	526		-	-	3
23&36	-	5	-	5		-	-	6	-	1		-	-	0	-	2
24	-	12	-	6	-	3	-	0	-	21	-	0	-	0	-	10
25		195	-	4	-	1	-	31	-	66	-	2		-		-
26	-	7		309	-	0	-	4	-	0	-	0	-	0		-
27	-	4		-		77	-	53	-	1		-	-	0		-
28	-	31	-	12	-	36		289	-	41	-	7	-	7	-	2
29	-	4	-	0	-	50	-	33		287	-	83	-	15	-	40
30	-	0	-	0		-	-	1	-	13		346	-	30	-	192
31	-	22	-	5	-	1	-	8	-	15	-	154		333	-	82
32	-	3		-		-	-	1	-	2	-	375	-	123		534
33	-	10	-	2		-	-	2	-	13	-	189	-	13	-	32
34	-	1		-		-	-	13	-	6	-	0	-	1		-
35		-		-		-	-	4	-	0		-	-	1		-
37		-		-		-		-		-		-		-		-
40		-		-		-		-		-		-		-		-
41		-		-		-		-		-		-		-		-
45		-	-	2		-		-		-		-		-		-
50		-		-		-		-		-		-		-		-
51	-	12	-	119	-	9	-	22	-	50	-	722	-	304	-	8
52		-		-		-		-		-		-		-		-
55		-		-		-		-		-		-		-		-
60		-		-		-		-		-		-		-		-
61		-		-		-		-		-		-		-		-
62		-		-		-		-		-		-		-		-
63		-		-		-		-		-		-		-		-
64		-		-		-		-		-	-	26		-	-	64
65		-		-		-		-		-	-	22		-		-
66		-		-		-		-		-		-		-		-
67		-		-		-		-		-		-		-		-
70		-	-	4		-		-		-		-		-		-
71	-	0	-	1	-	0	-	0	-	0	-	2	-	0	-	0
72		-		-		-		-		-	-	247	-	3	-	11
73	-	1	-	2	-	0	-	3	-	0	-	3	-	1	-	0
74	-	10	-	18	-	1	-	3	-	87	-	50	-	11	-	22
75		-		-		-		-		-		-		-		-
80		-		-		-		-		-		-		-		-
85		-		-		-		-		-		-		-		-
90		-	-	2		-		-		-		-		-		-
91		-		-		-		-		-		-		-		-
92		-		-		-		-		-		-		-		-
93		-		-		-		-		-		-		-		-
95		-		-		-		-		-		-		-		-

	precision and optical instruments	Motor vehicles and trailers	Other transport equipment	Recycling	Electricity and gas	Water collection and distribution	Construction work	Fuel and vehicle trade and repair
	33	**34**	**35**	**37**	**40**	**41**	**45**	**50**
1 - 5	-	-	-	-	-	-	-	-
10 - 13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	- 165	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	- 37	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	- 2	-	-	-	-	-	-	-
22	- 0	-	-	-	-	-	-	-
23&36	- 161	-	- 0	-	- 115	-	-	-
24	- 313	-	-	-	-	-	-	-
25	- 22	- 8	- 0	-	-	-	-	-
26	- 3	-	- 1	-	-	-	-	-
27	- 2	- 0	- 0	-	-	-	-	-
28	- 3	- 0	- 4	-	-	-	-	-
29	- 11	- 20	- 0	-	-	-	-	-
30	- 10	-	-	-	-	-	-	-
31	- 29	-	-	-	-	-	-	-
32	- 7	- 1	-	-	-	-	-	-
33	296	-	-	-	-	-	-	-
34	- 3	26	- 2	-	-	-	-	-
35	-	- 1	7	-	-	-	-	-
37	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	2	-
50	-	-	-	-	-	-	-	11
51	- 266	- 13	- 2	- 2	- 110	-	-	- 23
52	-	-	-	-	-	-	-	- 3
55	-	-	-	-	-	-	-	- 22
60	-	-	-	- 0	-	-	-	-
61	-	-	-	-	-	-	-	-
62	-	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	-
66	-	-	-	-	-	-	-	-
67	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-
71	- 2	- 0	- 106	- 0	- 0	-	- 322	- 48
72	-	-	-	-	-	-	-	-
73	- 39	- 0	- 5	- 0	- 0	-	-	-
74	- 57	- 2	- 40	- 0	- 0	-	-	-
75	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-
91	-	-	-	-	-	-	-	-
92	-	-	-	-	-	-	-	-
93	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-

		Wholesale trade 51		rade and repair of household goods 52		Hotel and restaurant services 55		Land transport services 60	Water transport services 61		Air transport services 62		t services and travel agencies 63		Post and telecommunication services 64
1 - 5		-		-		-		-	-		-		-		-
10 - 13		-		-		-		-	-		-		-		-
14		-		-		-		-	-		-		-		-
15	-	87		-		-		-	-		-		-		-
16		-		-		-		-	-		-		-		-
17		-		-		-		-	-		-		-		-
18		-		-		-		-	-		-		-		-
19		-		-		-		-	-		-		-		-
20		-		-		-		-	-		-		-		-
21		-		-		-		-	-		-		-		-
22		-		-		-		-	-		-		-		-
23&36		-		-		-		-	-		-		-		-
24		-		-		-		-	-		-		-		-
25		-		-		-		-	-		-		-		-
26		-		-		-		-	-		-		-		-
27		-		-		-		-	-		-		-		-
28		-		-		-		-	-		-		-		-
29		-		-		-		-	-		-		-		-
30		-		-		-		-	-		-		-		-
31		-		-		-		-	-		-		-		-
32		-		-		-		-	-		-		-		-
33		-		-		-		-	-		-		-		-
34		-		-		-		-	-		-		-		-
35		-		-		-		-	-		-		-		-
37		-		-		-		-	-		-		-		-
40		-		-		-		-	-		-		-		-
41		-		-		-		-	-		-		-		-
45		-		-		-		-	-		-		-		-
50		-		-		-		-	-		-		-		-
51		3,872	-	153	-	9	-	44	-	-	17		-	-	36
52	-	371		422	-	39	-	0	-		-		-		-
55		-	-	50		116	-	13	-		-		-		-
60		-		-		-		7	-		-		-		-
61		-		-		-		-	-		-		-		-
62		-		-		-		-	-		-		-		-
63		-		-		-	-	11	-		-		11		-
64		-	-	19		-		-	-	-	2		-		199
65	-	4		-		-		-	-	-	14		-		-
66		-		-		-		-	-		-		-		-
67		-		-		-		-	-		-		-		-
70		-		-		-		-	-		-		-		-
71	-	365	-	35		-		-	-		-		-		-
72		-		-	-	2		-	-		-		-	-	58
73		-		-		-		-	-		-		-		-
74	-	48		-	-	9		-	-	-	9	-	145		-
75		-		-		-		-	-		-		-		-
80		-		-		-		-	-		-		-		-
85		-		-		-		-	-		-		-		-
90		-		-		-		-	-		-		-		-
91		-		-		-		-	-		-		-		-
92		-		-		-		-	-		-		-		-
93		-	-	92		-		-	-		-		-		-
95		-		-		-		-	-		-		-		-

	Financial intermediation services	Insurance and pension services	y to financial intermediation	Real estate services	of machinery and equipment	Computer and related services	Research and development services	Other business services
	65	66	67	70	71	72	73	74
1 - 5	-	-	-	-	-	-	-	-
10 - 13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23&36	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-
30	-	-	-	-	-	- 51	-	-
31	-	-	-	-	-	- 3	-	-
32	-	-	-	-	-	- 20	-	-
33	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-
50	-	-	-	-	- 12	-	-	-
51	-	-	-	-	- 22	- 167	-	- 265
52	-	-	-	-	- 9	-	-	-
55	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-
61	-	-	-	-	-	-	-	-
62	-	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-	-
64	-	-	-	-	-	- 83	-	- 4
65	149	-	-	-	- 19	- 27	-	- 59
66	- 2	172	- 170	-	-	-	-	-
67	-	-	-	-	-	-	-	-
70	-	-	-	38	-	-	-	-
71	- 454	-	-	-	1,395	-	-	- 31
72	- 5	-	-	-	-	1,587	-	- 572
73	-	-	-	-	-	- 202	632	- 4
74	- 581	- 61	- 1	-	-	- 1,364	-	3,512
75	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-
91	-	-	-	-	-	-	-	-
92	-	-	-	-	-	-	-	-
93	-	-	-	-	-	-	-	-
95	-	-	-	-	-	-	-	-

	Public administration and defence 75	Education 80	Health and social work services 85	Sewage and refuse disposal services 90	Membership organisation services n.e.c. 91	Recreation 92	Other services 93	Households with employed persons 95
1 - 5	-	-	-	-	-	-	-	-
10 - 13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23&36	-	-	-	-	-	-	-	-
24	-	- -	32	-	-	-	-	-
25	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-
52	-	-	-	-	-	-	-	-
55	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-
61	-	-	-	-	-	-	-	-
62	-	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	-
66	-	-	-	-	-	-	-	-
67	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-
71	-	-	-	-	-	-	-	-
72	-	-	-	-	-	-	-	-
73	- -	295	-	-	-	-	-	-
74	-	-	-	-	-	-	-	-
75	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-
85	-	-	-	-	-	-	-	-
90	-	-	-	2	-	-	-	-
91	-	-	-	-	-	-	-	-
92	-	-	-	-	-	40	-	-
93	-	-	-	-	-	-	122	-
95	-	-	-	-	-	-	-	-

APPENDIX III: Sum of Supply Table and Transformation Matrix

	Product / *products*	Agriculture, forestry and fishing 1-5	Coal, peat, petroleum and metal ore extraction 10-13	Other mining and quarrying 14	Manufacture of food and beverages 15	Tobacco products 16
1 - 5	Agriculture, forestry and fishing	7200	0	0	0	0
10 - 13	Coal, peat, petroleum and metal ore extraction	0	690	0	0	0
14	Other mining and quarrying	0	0	762	0	0
15	Manufacture of food and beverages	0	0	0	16622	0
16	Tobacco products	0	0	0	0	221
17	Textiles	0	0	0	0	0
18	Wearing apparel	0	0	0	0	0
19	Leather and leather products	0	0	0	0	0
20	Wood and wood products (excl furniture)	0	0	0	0	0
21	Pulp, paper and paper products	0	0	0	0	0
22	Printed matter and recorded media	0	0	0	0	0
23&36	Petroleum and other manufacturing products	0	0	0	0	0
24	Chemical products and man-made fibres	0	0	0	0	0
25	Rubber and plastics	0	0	0	0	0
26	Other non-metallic mineral products	0	0	0	0	0
27	Basic metals	0	0	0	0	0
28	Fabricated metal products	0	0	0	0	0
29	Machinery and equipment n.e.c.	0	0	0	0	0
30	Office machinery and computers	0	0	0	0	0
31	Electrical machinery and apparatus n.e.c.	0	0	0	0	0
32	Radio, television and communications apparatus	0	0	0	0	0
33	Medical, precision and optical instruments	0	0	0	0	0
34	Motor vehicles and trailers	0	0	0	0	0
35	Other transport equipment	0	0	0	0	0
37	Recycling	0	0	0	0	0
40	Electricity and gas	0	0	0	0	0
41	Water collection and distribution	0	0	0	0	0
45	Construction work	0	0	0	0	0
50	Motor fuel and vehicle trade and repair	0	0	0	0	0
51	Wholesale trade	0	0	0	0	0
52	Retail trade and repair of household goods	0	0	0	0	0
55	Hotel and restaurant services	0	0	0	0	0
60	Land transport services	0	0	0	0	0
61	Water transport services	0	0	0	0	0
62	Air transport services	0	0	0	0	0
63	Auxiliary transport services and travel agencies	0	0	0	0	0
64	Post and telecommunication services	0	0	0	0	0
65	Financial intermediation services	0	0	0	0	0
66	Insurance and pension services	0	0	0	0	0
67	Services auxiliary to financial intermediation	0	0	0	0	0
70	Real estate services	0	0	0	0	0
71	Renting services of machinery and equipment	0	0	0	0	0
72	Computer and related services	0	0	0	0	0
73	Research and development services	0	0	0	0	0
74	Other business services	0	0	0	0	0
75	Public administration and defence	0	0	0	0	0
80	Education	0	0	0	0	0
85	Health and social work services	0	0	0	0	0
90	Sewage and refuse disposal services	0	0	0	0	0
91	Membership organisation services n.e.c.	0	0	0	0	0
92	Recreation	0	0	0	0	0
93	Other services	0	0	0	0	0
95	Private households with employed persons	0	0	0	0	0

	Textiles	Wearing apparel	Leather and leather products	Wood and wood products (excl furniture)	Pulp, paper and paper products	Printed matter and recorded media	Petroleum and other manufacturing products	Chemical products and man-made fibres
	17	**18**	**19**	**20**	**21**	**22**	**23, 36**	**24**
1 - 5	0	0	0	0	0	0	0	0
10 - 13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	630	0	0	0	0	0	0	0
18	0	213	0	0	0	0	0	0
19	0	0	29	0	0	0	0	0
20	0	0	0	1179	0	0	0	0
21	0	0	0	0	627	0	0	0
22	0	0	0	0	0	12963	0	0
23&36	0	0	0	0	0	0	2806	0
24	0	0	0	0	0	0	0	31625
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0

	Rubber and plastics 25	Other non-metallic mineral products 26	Basic metals 27	Fabricated metal products 28	Machinery and equipment n.e.c. 29	Office machinery and computers 30	Electrical machinery and apparatus n.e.c. 31	Radio, television and communications apparatus 32
1 - 5	0	0	0	0	0	0	0	0
10 - 13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23&36	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	1609	0	0	0	0	0	0	0
26	0	2302	0	0	0	0	0	0
27	0	0	726	0	0	0	0	0
28	0	0	0	2088	0	0	0	0
29	0	0	0	0	2009	0	0	0
30	0	0	0	0	0	12952	0	0
31	0	0	0	0	0	0	1732	0
32	0	0	0	0	0	0	0	4307
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0

	Medical, precision and optical instruments 33	Motor vehicles and trailers 34	Other transport equipment 35	Recycling 37	Electricity and gas 40	Water collection and distribution 41	Construction work 45	Motor fuel and vehicle trade and repair 50
1 - 5	0	0	0	0	0	0	0	0
10 - 13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23&36	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	5491	0	0	0	0	0	0	0
34	0	657	0	0	0	0	0	0
35	0	0	457	0	0	0	0	0
37	0	0	0	97	0	0	0	0
40	0	0	0	0	4122	0	0	0
41	0	0	0	0	0	283	0	0
45	0	0	0	0	0	0	38442	0
50	0	0	0	0	0	0	0	2294
51	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0

	Wholesale trade	Retail trade and repair of household goods	Hotel and restaurant services	Land transport services	Water transport services	Air transport services	Auxiliary transport services and travel agencies	Post and telecommunication services
	51	52	55	60	61	62	63	64
1 - 5	0	0	0	0	0	0	0	0
10 - 13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23&36	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	13342	0	0	0	0	0	0	0
52	0	7964	0	0	0	0	0	0
55	0	0	9800	0	0	0	0	0
60	0	0	0	3853	0	0	0	0
61	0	0	0	0	424	0	0	0
62	0	0	0	0	0	3108	0	0
63	0	0	0	0	0	0	4838	0
64	0	0	0	0	0	0	0	6956
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0

	Financial intermediation services 65	Insurance and pension services 66	Services auxiliary to financial intermediation 67	Real estate services 70	Renting services of machinery and equipment 71	Computer and related services 72	Research and development services 73	Other business services 74
1 - 5	0	0	0	0	0	0	0	0
10 - 13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23&36	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	14255	0	0	0	0	0	0	0
66	0	11944	0	0	0	0	0	0
67	0	0	4858	0	0	0	0	0
70	0	0	0	14750	0	0	0	0
71	0	0	0	0	5924	0	0	0
72	0	0	0	0	0	12941	0	0
73	0	0	0	0	0	0	1018	0
74	0	0	0	0	0	0	0	19611
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0

	Public administration and defence	Education	Health and social work services	Sewage and refuse disposal services	Membership organisation services n.e.c.	Recreation	Other services	Private households with employed persons
	75	80	85	90	91	92	93	95
1 - 5	0	0	0	0	0	0	0	0
10 - 13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23&36	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	10903	0	0	0	0	0	0	0
80	0	7838	0	0	0	0	0	0
85	0	0	15680	0	0	0	0	0
90	0	0	0	1466	0	0	0	0
91	0	0	0	0	958	0	0	0
92	0	0	0	0	0	2788	0	0
93	0	0	0	0	0	0	1124	0
95	0	0	0	0	0	0	0	136

APPENDIX IV: Input-Output Matrix for Imports (product by product)

	Product	1-5	10-13	14	15
1 - 5	Agriculture, forestry and fishing	201	0	0	256
10 - 13	Coal, peat, petroleum and metal ore extraction	3	62	5	2
14	Other mining and quarrying	5	0	24	0
15	Manufacture of food and beverages	356	0	0	1054
16	Tobacco products	0	0	0	0
17	Textiles	8	0	0	-1
18	Wearing apparel	2	0	1	0
19	Leather and leather products	1	0	0	-1
20	Wood and wood products (excl furniture)	1	1	-1	10
21	Pulp, paper and paper products	6	0	-3	218
22	Printed matter and recorded media	2	0	0	-1
23&36	Petroleum and other manufacturing products	118	6	33	67
24	Chemical products and man-made fibres	442	13	5	12
25	Rubber and plastics	7	3	0	119
26	Other non-metallic mineral products	1	1	-1	11
27	Basic metals	1	3	-8	31
28	Fabricated metal products	40	4	0	38
29	Machinery and equipment n.e.c.	86	12	-3	32
30	Office machinery and computers	7	0	0	4
31	Electrical machinery and apparatus n.e.c.	1	0	0	0
32	Radio, television and communications apparatus	0	0	0	0
33	Medical, precision and optical instruments	1	0	0	0
34	Motor vehicles and trailers	2	0	0	0
35	Other transport equipment	28	0	0	0
37	Recycling	0	0	0	0
40	Electricity and gas	1	0	0	2
41	Water collection and distribution	0	0	0	0
45	Construction work	0	0	0	0
50	Motor fuel and vehicle trade and repair	0	0	0	0
51	Wholesale trade	0	0	-1	511
52	Retail trade and repair of household goods	0	0	0	0
55	Hotel and restaurant services	0	0	0	0
60	Land transport services	0	1	3	5
61	Water transport services	1	0	0	0
62	Air transport services	0	0	5	13
63	Auxiliary transport services and travel agencies	0	0	0	-1
64	Post and telecommunication services	0	0	0	0
65	Financial intermediation services	0	0	0	30
66	Insurance and pension services	0	1	0	13
67	Services auxiliary to financial intermediation	0	0	0	0
70	Real estate services	0	0	0	0
71	Renting services of machinery and equipment	0	0	0	5
72	Computer and related services	0	0	0	-1
73	Research and development services	0	0	-1	-72
74	Other business services	-4	3	-8	2612
75	Public administration and defence	0	0	0	0
80	Education	0	0	0	0
85	Health and social work services	0	0	0	0
90	Sewage and refuse disposal services	0	0	0	0
91	Membership organisation services n.e.c.	0	0	0	0
92	Recreation	-2	0	0	0
93	Other services	0	0	0	0
95	Private households with employed persons	0	0	0	0
	Total	1316	110	53	4968

	16	17	18	19	20	21	22	23, 36
1 - 5	25	0	0	0	29	0	0	0
10 - 13	0	-2	0	0	-5	0	0	1142
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	-1	0
16	0	0	0	0	0	0	0	0
17	0	180	26	4	1	1	7	7
18	0	-9	61	0	0	0	0	0
19	0	0	0	5	0	0	-1	0
20	1	-2	0	0	130	1	1	75
21	5	3	1	0	5	155	148	15
22	0	0	0	0	0	1	49	0
23&36	0	3	0	0	3	1	-4	310
24	0	56	1	0	42	23	85	3
25	0	1	0	0	3	8	3	20
26	0	0	0	0	0	0	2	16
27	0	-6	1	0	6	0	4	-15
28	0	1	1	0	16	2	2	20
29	0	2	0	0	13	2	14	-3
30	0	0	0	0	0	0	-3	-3
31	0	0	0	0	0	0	-5	3
32	0	0	0	0	0	0	-6	0
33	0	0	0	0	0	0	-1	0
34	0	0	0	0	0	0	-1	0
35	0	0	0	0	0	0	-1	0
37	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	-1	0	0	0	-1	3828	10
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	0	0	0	1	0	0	0
61	0	0	0	0	0	0	0	0
62	0	0	0	0	0	1	14	2
63	0	0	0	0	0	0	-1	0
64	0	0	0	0	0	0	73	0
65	0	0	0	0	0	0	1	2
66	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	-1	0
72	0	0	0	0	0	0	-40	1
73	0	-1	0	0	0	-1	937	-2
74	6	-4	0	0	-1	-3	3220	17
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0
	39	224	91	9	245	191	8322	1620

	24	25	26	27	28	29	30	31
1 - 5	1	0	0	0	0	0	0	0
10 - 13	4	-2	10	61	-8	0	3	0
14	3	0	15	1	0	0	0	0
15	46	1	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	2	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0
19	3	0	0	0	0	0	0	0
20	1	10	4	0	1	0	0	0
21	78	5	19	1	4	3	6	0
22	2	0	0	0	0	0	-2	-1
23&36	7	20	26	37	0	1	-3	3
24	3537	90	34	21	10	3	47	7
25	46	231	9	0	8	16	3	8
26	3	7	108	0	4	2	1	1
27	8	27	49	90	497	159	11	5
28	15	30	17	5	78	135	22	5
29	83	32	30	4	52	244	32	2
30	8	1	0	0	1	-6	5606	53
31	0	-6	-1	-1	-3	23	235	418
32	1	-1	0	0	-3	3	483	86
33	5	-2	0	0	0	0	2	-3
34	0	0	0	0	-1	0	1	0
35	0	0	0	0	-1	1	1	0
37	0	0	0	0	0	0	0	0
40	2	0	1	0	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	131	-2	-1	0	-1	2	1574	62
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	1	1	0	1	0	0	-1
61	0	0	0	0	0	0	0	0
62	21	1	5	1	2	1	5	4
63	0	0	0	0	0	0	0	0
64	2	0	0	0	0	0	1	0
65	0	0	0	0	0	0	3	1
66	4	0	0	2	0	1	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	6	1
72	7	0	0	0	0	1	-6	-1
73	2332	-1	0	-1	-1	25	22	-5
74	11172	-13	-2	-4	-6	108	2866	311
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0
	17525	428	323	218	632	719	10920	956

	32	33	34	35	37	40	41	45
1 - 5	0	-3	0	0	0	0	0	13
10 - 13	0	-69	0	1	0	412	0	1
14	0	0	0	0	0	0	0	71
15	0	-10	0	0	0	3	0	5
16	0	0	0	0	0	0	0	0
17	0	-8	0	0	0	0	0	85
18	0	1	0	0	0	0	0	24
19	1	0	0	0	0	0	0	16
20	2	-4	0	0	0	-3	0	457
21	9	16	0	0	0	2	1	43
22	1	0	0	0	0	2	1	26
23&36	1	-15	0	0	0	453	2	307
24	128	164	4	1	1	6	6	332
25	10	122	10	1	0	0	2	618
26	2	-1	0	0	0	0	0	626
27	6	48	50	24	36	1	2	236
28	20	24	9	0	0	15	1	647
29	87	50	6	-1	0	23	11	501
30	145	24	4	0	0	19	1	102
31	137	112	26	21	0	21	0	695
32	1029	63	115	0	0	4	1	70
33	39	1081	0	4	0	4	2	74
34	0	0	33	-1	0	1	0	38
35	0	0	1	119	0	0	0	38
37	0	0	0	0	0	0	0	0
40	1	0	0	0	0	11	0	1
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	9
50	0	0	0	0	0	0	0	0
51	182	254	0	0	0	-1	0	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	2
61	0	0	0	0	0	0	0	0
62	7	3	1	0	0	0	0	2
63	1	0	0	0	0	0	0	1
64	2	5	0	0	0	0	0	0
65	0	0	0	-5	0	0	0	-16
66	1	5	0	1	0	0	0	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	1	0	-13	0	0	0	-40
72	1	8	0	0	0	8	0	0
73	115	42	0	0	0	0	0	0
74	40	353	-1	9	0	44	0	-8
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0
	1965	2268	259	162	37	1024	29	4978

	50	51	52	55	60	61	62	63
1 - 5	0	-2	1	28	0	0	0	0
10 - 13	0	0	0	1	0	0	0	0
14	0	0	0	0	0	0	0	1
15	1	4	44	1474	1	1	5	7
16	0	0	0	0	0	0	0	0
17	4	4	19	21	1	0	1	1
18	0	0	1	17	1	0	1	1
19	11	3	6	14	1	0	1	0
20	0	0	2	8	0	0	0	1
21	1	7	9	17	3	0	0	1
22	1	26	2	5	1	0	0	2
23&36	19	69	33	57	176	11	232	37
24	3	6	18	27	2	0	1	4
25	14	20	14	6	21	0	2	6
26	1	5	2	2	1	0	1	1
27	1	1	4	0	5	0	0	0
28	3	1	3	2	4	0	0	1
29	15	3	18	1	6	0	2	2
30	0	0	0	1	1	0	1	1
31	1	2	5	1	13	0	2	1
32	2	2	1	1	2	0	2	3
33	1	1	0	1	0	0	2	2
34	66	4	7	4	29	0	1	3
35	2	1	0	4	22	18	106	18
37	0	0	0	0	0	0	0	0
40	0	0	1	2	0	0	0	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	0	97	-1	0	0	2	7	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	-2	0	0	942
60	1	39	1	1	2	0	0	2
61	0	1	0	2	0	6	2	3
62	1	2	1	6	-1	0	43	758
63	2	16	4	7	11	3	11	21
64	0	-1	16	0	3	0	1	1
65	-2	-27	-2	0	0	0	19	0
66	0	0	0	0	0	0	10	0
67	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
71	-6	-51	-3	0	0	1	136	0
72	0	13	3	0	0	0	2	4
73	0	0	0	0	0	0	0	-1
74	-2	451	130	-3	2	18	248	-4
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	1	0	0	0	0
95	0	0	0	0	0	0	0	0
	140	701	340	1708	305	63	840	1819

	64	65	66	67	70	71	72	73
1 - 5	0	0	0	0	1	0	0	0
10 - 13	0	0	0	0	0	0	0	0
14	0	0	0	0	1	0	0	0
15	7	3	1	3	0	1	10	2
16	0	0	0	0	0	0	0	0
17	2	0	0	0	17	1	1	3
18	3	1	1	1	1	2	3	4
19	2	0	0	1	0	1	1	4
20	2	0	0	0	31	1	1	0
21	2	2	2	4	8	2	2	3
22	2	4	2	2	3	1	3	1
23&36	15	4	9	4	10	22	29	5
24	1	0	0	1	9	1	0	8
25	52	2	1	2	16	2	19	2
26	3	0	0	0	26	0	0	0
27	7	0	0	0	0	0	4	0
28	2	0	0	1	8	1	2	0
29	15	-4	1	1	8	62	22	2
30	9	2	0	0	29	3	36	3
31	70	0	1	1	4	6	46	1
32	472	0	1	2	3	5	66	3
33	20	0	0	1	1	2	23	1
34	5	-1	2	2	5	30	16	1
35	5	0	0	1	1	3	7	1
37	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	1	0
41	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
51	-5	-1	0	0	0	0	955	0
52	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0
60	1	0	0	0	0	1	1	0
61	2	0	0	0	0	0	0	0
62	11	7	2	1	2	3	2	1
63	3	2	1	1	2	2	0	0
64	260	4	345	-5	0	0	-3	0
65	0	2358	22	0	0	295	-4	0
66	0	61	5361	310	0	1	-1	0
67	0	84	184	11	0	0	0	0
70	0	0	0	0	0	0	0	0
71	0	39	3	0	0	729	0	0
72	43	66	18	4	0	3	686	0
73	-2	-2	0	0	0	0	353	0
74	-4	1067	205	249	0	151	2345	0
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0
	1008	3701	6163	597	187	1330	4624	49

	74	75	80	85	90	91	92	93	95
1 - 5	0	1	5	2	0	0	0	0	0
10 - 13	0	22	1	0	0	0	1	0	0
14	0	0	0	0	1	0	0	0	0
15	27	19	1	22	3	15	10	0	0
16	0	0	0	0	0	0	0	0	0
17	9	7	-1	25	1	1	2	3	0
18	11	50	-1	4	3	3	6	8	0
19	13	1	-1	0	4	3	4	4	0
20	5	1	5	1	0	1	1	0	0
21	38	19	48	60	4	1	2	1	0
22	30	6	13	2	2	1	2	1	0
23&36	70	86	36	117	8	3	7	6	0
24	25	57	24	997	49	7	20	20	0
25	14	21	1	131	11	2	3	2	0
26	1	8	0	1	5	1	2	0	0
27	2	4	0	0	2	0	0	0	0
28	2	14	11	1	3	0	1	0	0
29	27	13	0	1	4	1	2	3	0
30	11	26	29	1	5	0	7	0	0
31	8	1	0	24	2	1	2	1	0
32	9	4	0	13	2	1	9	2	0
33	10	14	26	263	1	1	1	0	0
34	19	5	0	1	4	0	1	1	0
35	11	27	0	2	4	1	2	1	0
37	0	0	0	0	0	0	0	0	0
40	2	2	2	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	10	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0
60	1	4	1	1	1	0	0	0	0
61	0	1	0	0	1	0	0	0	0
62	34	6	12	4	0	1	1	0	0
63	10	0	0	0	1	0	1	0	0
64	4	0	0	0	0	0	0	0	0
65	-10	0	0	0	0	0	0	0	0
66	12	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0
71	3	0	0	0	0	0	0	0	0
72	74	0	0	0	0	0	1	0	0
73	80	0	15	-2	0	0	0	0	0
74	2971	0	0	-11	0	0	21	0	0
75	0	30	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0
91	0	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	111	0	0
93	2	0	1	0	1	0	0	1	0
95	0	0	0	0	0	0	0	0	0
	3533	448	229	1661	120	45	219	58	0

APPENDIX V: IO Coefficient Matrix for Domestic and Imported Product Flow#

		1-5	10-13	14	15	16
1 - 5	Agriculture, forestry and fishing	0.22578	0.00001	0.00012	0.25572	0.12185
10 - 13	Coal, peat, petroleum and metal ore extraction	0.00052	0.16190	0.01416	0.00021	0.00000
14	Other mining and quarrying	0.00422	0.00429	0.18481	0.00000	0.00000
15	Manufacture of food and beverages	0.12241	-0.00005	-0.00011	0.11857	0.00000
16	Tobacco products	0.00000	0.00000	0.00000	0.00000	0.01303
17	Textiles	0.00121	-0.00001	-0.00010	-0.00003	0.00000
18	Wearing apparel	0.00030	0.00049	0.00096	-0.00001	0.00000
19	Leather and leather products	0.00011	-0.00004	-0.00001	-0.00003	0.00000
20	Wood and wood products (excl furniture)	0.00026	0.00160	-0.00074	0.00124	0.00616
21	Pulp, paper and paper products	0.00117	0.00003	-0.00351	0.01856	0.02929
22	Printed matter and recorded media	0.00204	-0.00003	0.00000	-0.00003	0.00008
23&36	Petroleum and other manufacturing products	0.02275	0.01125	0.05913	0.00552	0.00053
24	Chemical products and man-made fibres	0.06808	0.02077	0.00748	0.00080	0.00193
25	Rubber and plastics	0.00144	0.00620	0.00048	0.01058	0.00008
26	Other non-metallic mineral products	0.00045	0.00294	0.03153	0.00212	0.00000
27	Basic metals	0.00015	0.00486	-0.00988	0.00217	0.00000
28	Fabricated metal products	0.01208	0.01317	0.00269	0.00499	0.00220
29	Machinery and equipment n.e.c.	0.01277	0.01916	-0.00320	0.00206	0.00199
30	Office machinery and computers	0.00105	-0.00002	0.00015	0.00024	0.00000
31	Electrical machinery and apparatus n.e.c.	0.00012	0.00001	0.00022	-0.00001	0.00000
32	Radio, television and communications apparatus	0.00004	0.00004	0.00003	-0.00002	0.00000
33	Medical, precision and optical instruments	0.00022	0.00056	0.00042	-0.00002	0.00000
34	Motor vehicles and trailers	0.00029	0.00035	-0.00006	-0.00001	0.00000
35	Other transport equipment	0.00391	-0.00008	0.00000	-0.00001	0.00000
37	Recycling	0.00001	0.00000	0.00002	0.00051	0.00000
40	Electricity and gas	0.01301	0.03483	0.02810	0.01061	0.00351
41	Water collection and distribution	0.00073	0.00043	0.00022	0.00058	0.00035
45	Construction work	0.01073	0.02372	0.02669	0.00101	0.00069
50	Motor fuel and vehicle trade and repair	0.00408	0.00942	0.00840	0.00079	0.00034
51	Wholesale trade	0.05031	0.02230	0.04067	0.05979	0.00967
52	Retail trade and repair of household goods	0.00002	0.00000	0.00000	0.00000	0.00000
55	Hotel and restaurant services	0.00596	0.00274	0.01514	0.00803	0.01763
60	Land transport services	0.00256	0.04343	0.23851	0.02145	0.00702
61	Water transport services	0.00083	0.00056	0.00321	0.00027	0.00020
62	Air transport services	0.00040	0.00288	0.03823	0.00483	0.01312
63	Auxiliary transport services and travel agencies	0.00085	0.00007	0.00081	0.00027	0.00248
64	Post and telecommunication services	0.00441	0.00126	0.00760	0.00415	0.01181
65	Financial intermediation services	0.02445	0.04956	0.03488	0.02485	0.01536
66	Insurance and pension services	0.01590	0.01843	0.01918	0.00408	0.02369
67	Services auxiliary to financial intermediation	0.00001	0.00445	0.00324	0.00221	0.00143
70	Real estate services	0.00180	0.00182	0.00032	0.00033	0.00333
71	Renting services of machinery and equipment	0.00168	0.00287	0.07609	0.00147	0.00015
72	Computer and related services	0.00037	0.02148	0.01184	0.00189	0.01981
73	Research and development services	0.00023	0.00055	-0.00125	-0.00392	0.00000
74	Other business services	0.00322	0.07358	-0.00790	0.19757	0.03709
75	Public administration and defence	0.00604	0.00144	0.00129	0.00056	0.00113
80	Education	0.00001	0.00000	0.00000	0.00006	0.00019
85	Health and social work services	0.01294	0.00003	0.00000	0.00050	0.00141
90	Sewage and refuse disposal services	0.00061	0.00144	0.00100	0.00217	0.00469
91	Membership organisation services n.e.c.	0.00187	0.00000	0.00000	0.00007	0.00089
92	Recreation	0.00085	0.00020	0.00083	0.00070	0.00039
93	Other services	0.00094	0.00709	0.00720	0.00109	0.00007
95	Private households with employed persons	0.00000	0.00000	0.00000	0.00000	0.00000

2005 IO Table for Domestic Product Flow can be obtained from Central Statistics Office (2009)

#IO Coefficient Matrix $_{\text{(Domestic + Imported)}}$ or Matrix A, is derived from sum of IO Matrix for Imports and IO Matrix for Domestic Product Flow

	17	18	19	20	21	22	23, 36	24
1 - 5	0.00070	0.00099	0.00274	0.11513	-0.00001	0.00005	0.00000	0.00029
10 - 13	-0.00624	0.00415	-0.00149	-0.00428	-0.00067	0.00000	0.41934	0.00024
14	-0.00015	0.00016	0.00000	0.00006	-0.00002	0.00000	0.00023	0.00065
15	0.00130	-0.00022	-0.00011	-0.00002	0.00132	-0.00011	0.00000	0.00269
16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17	0.50149	0.13632	0.15064	0.00139	0.00274	0.00056	0.00267	0.00009
18	-0.02466	0.29247	-0.00001	0.00001	0.00000	-0.00002	0.00012	0.00004
19	0.00011	-0.00007	0.16376	0.00001	0.00000	-0.00005	-0.00006	0.00010
20	-0.00400	0.00184	-0.00027	0.21810	0.00282	0.00017	0.05403	0.00007
21	0.00933	0.00806	0.00688	0.00600	0.34986	0.01576	0.00788	0.00348
22	0.00028	0.00004	-0.00045	0.00063	0.01442	0.03475	0.00024	0.00058
23&36	0.01049	-0.00108	-0.00158	0.00416	0.00129	-0.00027	0.15860	0.00029
24	0.15656	0.00503	-0.00125	0.03998	0.04185	0.00723	0.00129	0.12393
25	0.00491	0.00063	-0.00389	0.00420	0.01796	0.00034	0.01676	0.00215
26	0.00104	-0.00018	-0.00022	0.00041	-0.00006	0.00051	0.01839	0.00034
27	-0.01548	0.00288	-0.00043	0.00597	-0.00067	0.00035	-0.00112	0.00028
28	0.00452	0.00749	0.01567	0.02997	0.00719	0.00031	0.01587	0.00103
29	0.00619	0.00114	0.00519	0.01176	0.00438	0.00114	-0.00082	0.00280
30	0.00059	-0.00012	0.00000	0.00002	0.00065	-0.00018	-0.00111	0.00028
31	0.00001	0.00001	0.00005	-0.00017	0.00006	-0.00040	0.00118	-0.00001
32	0.00002	-0.00002	-0.00003	-0.00004	0.00001	-0.00047	-0.00005	0.00003
33	-0.00002	0.00003	0.00000	0.00000	0.00006	-0.00011	-0.00011	0.00016
34	-0.00002	0.00018	-0.00008	0.00005	0.00000	-0.00008	0.00002	0.00000
35	0.00002	0.00045	-0.00001	0.00000	0.00000	-0.00005	0.00004	0.00001
37	-0.00001	0.00057	0.00001	0.00377	0.00739	0.00000	0.00013	0.00000
40	0.01430	0.00535	0.00281	0.02450	0.01269	0.00063	0.00601	0.00430
41	0.00304	0.00075	0.00000	0.00234	0.00221	0.00124	0.00063	0.00094
45	0.00083	0.00158	0.00074	0.01108	0.00205	0.00066	0.00169	0.00034
50	0.00090	0.00060	0.00006	0.00116	0.00098	0.00010	0.00085	0.00016
51	0.03268	0.02465	0.02354	0.03782	0.01697	0.29713	0.03061	0.01259
52	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
55	0.00950	0.01091	0.03029	0.00807	0.01444	0.00338	0.00896	0.00285
60	0.01884	0.00994	0.03922	0.03522	0.02762	0.00257	0.00940	0.00030
61	0.00026	0.00010	0.00029	0.00043	0.00039	0.00005	0.00015	0.00003
62	0.00484	0.00075	0.00074	-0.00003	0.00482	0.00596	0.00525	0.00393
63	0.00009	0.00058	0.00066	0.00021	0.00073	0.00015	0.00057	0.00009
64	0.00790	0.00601	0.01168	0.00644	0.00603	0.00685	0.00326	0.00090
65	0.01898	0.01417	0.02527	0.00499	0.01313	0.01072	0.01064	0.00999
66	0.01301	0.01922	0.04536	0.00991	0.01856	0.00434	0.01048	0.00434
67	0.00175	0.00121	0.00234	0.00046	0.00122	0.00069	0.00099	0.00088
70	0.00106	0.00015	0.00261	0.00068	0.00181	0.00029	0.00031	0.00006
71	0.00129	0.00355	0.00130	0.00340	0.00230	0.00040	0.00064	0.00031
72	0.00722	0.00128	0.02970	0.00483	0.00931	-0.00026	0.00727	0.01739
73	0.00136	0.00066	0.00591	0.00201	0.00010	0.07362	-0.00018	0.07433
74	0.00473	0.07394	0.05788	0.03243	0.03820	0.25664	0.03895	0.35589
75	0.00214	0.00355	0.00634	0.00152	0.00094	0.00007	0.00157	0.00018
80	0.00008	0.00014	0.00000	0.00001	0.00009	0.00002	0.00008	0.00013
85	0.00081	0.00119	0.00008	0.00017	0.00079	0.00026	0.00063	0.00146
90	0.00580	0.00924	0.02559	0.00708	0.00089	0.00004	0.00043	0.00039
91	0.00000	0.00013	0.00000	0.00000	0.00023	0.00009	0.00011	0.00003
92	0.00176	0.00160	0.00137	0.00023	0.00124	0.00027	0.00051	0.00033
93	0.00343	0.00142	0.00644	0.00240	0.00633	0.00012	0.00159	0.00013
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	25	26	27	28	29	30	31	32
1 - 5	-0.00013	0.00008	0.00007	-0.00016	0.00017	0.00022	0.00054	-0.00001
10 - 13	-0.00120	0.00676	0.17813	-0.00380	-0.00003	0.00020	0.00020	-0.00009
14	0.00001	0.04021	0.01175	-0.00006	0.00026	0.00000	0.00034	0.00000
15	0.00168	-0.00001	-0.00001	-0.00002	-0.00005	-0.00001	-0.00003	-0.00001
16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17	-0.00023	0.00015	0.00002	-0.00009	-0.00017	0.00002	-0.00006	0.00003
18	0.00019	-0.00006	-0.00001	0.00000	-0.00002	-0.00001	-0.00003	0.00004
19	0.00000	-0.00003	0.00000	0.00001	-0.00004	0.00000	-0.00007	0.00023
20	0.01225	0.00293	0.00035	0.00109	0.00021	0.00003	-0.00005	0.00086
21	0.00417	0.01197	0.00200	0.00254	0.00192	0.00065	0.00009	0.00311
22	0.00031	0.00041	0.00012	0.00019	0.00022	0.00071	-0.00039	0.00125
23&36	0.01742	0.01533	0.07063	0.00020	0.00050	-0.00017	0.00270	0.00031
24	0.06170	0.01658	0.03167	0.00522	0.00172	0.00403	0.00417	0.03301
25	0.20108	0.00572	0.00009	0.00594	0.01204	0.00036	0.00680	0.00329
26	0.01289	0.14992	-0.00019	0.00670	0.00285	0.00013	0.00098	0.00122
27	0.01912	0.02428	0.12572	0.27452	0.08079	0.00107	0.00346	0.00157
28	0.04051	0.01618	0.01764	0.08089	0.11817	0.00374	0.00588	0.01056
29	0.02121	0.01387	0.00605	0.02657	0.12306	0.00265	0.00134	0.02150
30	0.00039	0.00000	0.00021	0.00041	-0.00308	0.45021	0.03187	0.03514
31	-0.00368	-0.00041	-0.00133	-0.00155	0.01127	0.02150	0.27512	0.03758
32	-0.00063	-0.00008	-0.00014	-0.00166	0.00181	0.04850	0.06114	0.29647
33	-0.00122	0.00000	0.00001	-0.00010	0.00011	0.00019	-0.00148	0.01034
34	0.00010	0.00016	0.00002	-0.00036	-0.00009	0.00010	-0.00010	-0.00001
35	0.00003	-0.00001	0.00001	-0.00063	0.00038	0.00006	-0.00018	0.00004
37	0.00000	0.00000	0.03874	0.00582	0.00000	0.00000	0.00000	0.00000
40	0.02274	0.03645	0.03781	0.00715	0.00766	0.00045	0.00687	0.01293
41	0.00070	0.00049	0.00716	0.00044	0.00277	0.00002	0.00004	0.00018
45	0.00102	0.00013	0.00139	0.00234	0.00087	0.00018	0.00915	0.00338
50	0.00172	0.00188	0.00553	0.00096	0.00036	0.00012	0.00403	0.00151
51	0.03362	0.04919	0.03812	0.03146	0.03673	0.13075	0.05400	0.05777
52	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
55	0.01421	0.00837	0.00442	0.00722	0.00905	0.00484	0.00741	0.00121
60	0.02625	0.02904	0.00420	0.01396	0.01232	0.00686	0.01023	0.00103
61	0.00039	0.00045	0.00011	0.00020	0.00017	0.00010	0.00005	0.00011
62	0.00537	0.01339	0.00928	0.00429	0.00293	0.00225	0.01195	0.00946
63	0.00143	0.00074	0.00022	0.00053	0.00015	0.00012	0.00140	0.00632
64	0.01408	0.01397	0.00318	0.00575	0.00688	0.00041	0.00556	0.00067
65	0.00130	0.03454	0.02302	0.02986	0.02913	0.00523	0.00906	0.00319
66	0.01979	0.01080	0.00945	0.00905	0.01377	0.00073	0.00873	0.00383
67	0.00009	0.00317	0.00215	0.00275	0.00247	0.00037	0.00080	0.00028
70	0.00189	0.00034	0.00021	0.00065	0.00011	0.00004	0.00044	0.00005
71	0.00326	0.00835	0.00085	0.00792	0.00177	0.00052	0.00190	0.00111
72	0.00961	0.00481	0.00035	0.00473	0.00429	0.00265	0.04960	0.00641
73	0.00163	0.00092	0.00022	0.00138	0.01360	0.00301	0.00457	0.03224
74	0.04863	0.04331	0.00744	0.01795	0.05829	0.23095	0.19579	0.01256
75	0.00120	0.00126	0.00232	0.00212	0.00082	0.00019	0.00105	0.00050
80	0.00014	0.00003	0.00006	0.00006	0.00010	0.00009	0.00015	0.00038
85	0.00117	0.00045	0.00033	0.00074	0.00109	0.00056	0.00122	0.00197
90	0.00232	0.00120	0.01483	0.01302	0.00006	0.00001	0.00019	0.00005
91	0.00033	0.00000	0.00000	0.00008	0.00016	0.00001	0.00020	0.00005
92	0.00042	0.00112	0.00065	0.00033	0.00055	0.00070	0.00055	0.00094
93	0.00308	0.00319	0.00047	0.00302	0.00167	0.00004	0.00123	0.00027
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	33	34	35	37	40	41	45	50
1 - 5	-0.00043	0.00006	0.00000	0.00003	0.00006	0.00000	0.00197	0.00014
10 - 13	-0.01262	0.00002	0.00143	0.00000	0.11198	0.00007	**0.00004**	0.00008
14	0.00000	0.00000	-0.00001	0.00000	0.00000	0.00000	0.01154	0.00000
15	-0.00170	-0.00002	-0.00017	-0.00001	0.00135	0.00268	0.00026	0.00052
16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
17	-0.00147	0.00007	-0.00008	-0.00001	-0.00007	0.00000	0.00244	0.00184
18	0.00027	0.00000	-0.00016	-0.00001	0.00000	0.00000	0.00065	0.00019
19	0.00004	-0.00001	-0.00012	-0.00001	0.00000	0.00000	0.00044	0.00495
20	-0.00066	0.00014	-0.00007	0.00000	-0.00068	0.00015	0.02353	0.00022
21	0.00382	0.00097	-0.00011	0.00173	0.00079	0.00519	0.00158	0.00071
22	0.00057	0.00012	0.00001	0.00003	0.00345	0.01489	0.00511	0.00288
23&36	-0.00250	0.00104	0.00067	0.00179	0.15064	0.00824	**0.01185**	0.01169
24	0.03265	0.00605	0.00147	0.00744	0.00155	0.02319	0.00957	0.00144
25	0.03113	0.02273	0.00426	0.00002	0.00009	0.00898	0.02383	0.00900
26	0.00012	0.00025	0.00000	-0.00001	0.00000	0.00203	0.05257	0.00139
27	0.00974	0.08774	0.05836	0.42647	0.00037	0.00616	0.00708	0.00040
28	0.00874	0.02956	0.00169	0.00590	0.00824	0.00522	0.03698	0.00323
29	0.00961	0.00947	-0.00190	0.00545	0.00606	0.04121	0.01389	0.00690
30	0.00461	0.00607	0.00027	-0.00001	0.00485	0.00350	0.00278	0.00015
31	0.02364	0.04742	0.05299	-0.00002	0.00602	0.00015	0.02140	0.00077
32	0.01394	0.21742	0.00072	-0.00001	0.00112	0.00337	0.00227	0.00082
33	0.22062	0.00049	0.01072	-0.00001	0.00102	0.00666	0.00221	0.00070
34	0.00003	0.05166	-0.00142	-0.00004	0.00026	0.00169	0.00102	0.02965
35	-0.00001	0.00222	0.26339	-0.00003	0.00000	0.00000	0.00099	0.00069
37	0.00000	0.00036	0.00000	0.05621	0.00000	0.00000	0.00050	0.00000
40	0.00464	0.00539	0.01022	0.01190	0.23370	0.06819	**0.00344**	0.00893
41	0.00103	0.01360	0.00067	0.00027	0.00000	0.01404	0.00058	0.00042
45	0.00041	0.00070	0.00767	0.00050	0.00616	0.06258	0.26197	0.00075
50	0.00020	0.01614	0.00132	0.00031	0.00005	0.00646	0.00172	0.01821
51	0.05867	0.04926	0.01357	0.03648	0.03141	0.02062	0.03000	0.00603
52	0.00000	0.00000	0.00000	0.00000	0.00000	0.00013	0.00000	0.00000
55	0.00720	0.01243	0.00739	0.00000	0.00099	0.00908	0.00297	0.00370
60	0.00226	0.00852	0.00147	0.07165	0.00002	0.00336	0.00235	0.01505
61	0.00003	0.00017	0.00010	0.00090	0.00001	0.00000	0.00008	0.00185
62	0.00314	0.01070	0.00468	-0.00001	0.00000	0.00000	0.00037	0.00273
63	0.00088	0.00054	0.00176	-0.00003	0.00011	0.00548	0.00045	0.01459
64	0.00445	0.00723	0.00087	0.00000	0.00203	0.01538	0.00162	0.01716
65	0.00260	0.02000	-0.00046	0.01959	0.03280	0.01978	0.00810	0.02050
66	0.00851	0.01607	0.01431	0.03222	0.00028	0.02105	0.00133	0.02284
67	0.00012	0.00185	0.00071	0.00179	0.00304	0.00059	0.00064	0.00037
70	0.00031	0.00079	0.00019	0.00275	0.00014	0.01574	0.01687	0.01918
71	0.00035	0.00081	-0.02835	0.00208	0.00241	0.01437	0.01407	0.00432
72	0.00703	0.00639	0.00053	0.02261	0.00587	0.02770	0.00395	0.01247
73	0.01641	0.00322	-0.00009	0.00005	0.00002	0.00522	0.00038	0.00009
74	0.07551	0.02489	0.02740	0.01762	0.02052	0.17166	0.03045	0.04998
75	0.00048	0.00135	0.00120	0.00316	0.00058	0.00112	0.00621	0.00358
80	0.00001	0.00009	0.00013	0.00000	0.00008	0.00208	0.00007	0.00008
85	0.00087	0.00050	0.00105	0.00000	0.00061	0.00170	0.00048	0.00060
90	0.00020	0.00164	0.00100	0.00000	0.00451	0.03646	0.00499	0.00444
91	0.00011	0.00024	0.00024	0.00000	0.00001	0.00184	0.00002	0.00002
92	0.00105	0.00017	0.00206	0.00000	0.00014	0.00078	0.00019	0.00058
93	0.00028	0.00127	0.00114	0.00721	0.00028	0.00018	0.00007	0.00048
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	51	52	55	60	61	62	63	64
1 - 5	0.00005	0.00121	0.02691	-0.00001	0.00454	0.00001	0.00001	0.00003
10 - 13	0.00000	0.00007	0.00013	0.00007	0.00000	0.00000	0.00000	0.00000
14	0.00012	0.00006	0.00028	0.00011	0.00001	0.00001	0.00075	0.00003
15	0.00058	0.01030	0.28204	0.00063	0.00433	0.00301	0.00270	0.00194
16	0.00000	0.00000	0.00018	0.00000	0.00000	0.00000	0.00000	0.00000
17	0.00032	0.00258	0.00232	0.00015	0.00008	0.00042	0.00012	0.00029
18	0.00003	0.00014	0.00182	0.00025	0.00000	0.00035	0.00011	0.00037
19	0.00022	0.00087	0.00150	0.00027	0.00003	0.00026	0.00005	0.00027
20	0.00007	0.00043	0.00152	0.00008	0.00016	0.00000	0.00026	0.00050
21	0.00072	0.00159	0.00249	0.00104	0.00000	0.00022	0.00040	0.00038
22	0.00245	0.00213	0.00376	0.00153	0.00044	0.00108	0.00382	0.00230
23&36	0.00712	0.00581	0.00832	0.06310	0.03610	0.10251	0.01066	0.00313
24	0.00049	0.00256	0.00304	0.00056	0.00014	0.00051	0.00088	0.00022
25	0.00222	0.00255	0.00094	0.00802	0.00138	0.00084	0.00189	0.01104
26	0.00117	0.00065	0.00063	0.00079	0.00019	0.00061	0.00041	0.00146
27	0.00010	0.00052	0.00000	0.00156	0.00010	0.00008	0.00006	0.00113
28	0.00023	0.00083	0.00041	0.00228	0.00207	0.00028	0.00034	0.00079
29	0.00027	0.00237	0.00007	0.00168	0.00074	0.00056	0.00034	0.00234
30	0.00000	0.00002	0.00008	0.00035	0.00058	0.00043	0.00013	0.00141
31	0.00021	0.00075	0.00008	0.00387	0.00076	0.00091	0.00033	0.01188
32	0.00022	0.00015	0.00013	0.00070	0.00001	0.00081	0.00082	0.08463
33	0.00012	0.00006	0.00014	0.00009	0.00007	0.00061	0.00037	0.00335
34	0.00031	0.00090	0.00046	0.00775	0.00017	0.00028	0.00074	0.00068
35	0.00005	0.00002	0.00040	0.00581	0.04306	0.03469	0.00377	0.00073
37	0.00000	0.00000	0.00000	0.00000	0.00015	0.00001	0.00003	0.00013
40	0.00315	0.01609	0.01636	0.00335	0.00309	0.00225	0.00434	0.00399
41	0.00024	0.00052	0.00061	0.00009	0.00011	0.00015	0.00020	0.00012
45	0.00064	0.00305	0.00292	0.00088	0.00058	0.00053	0.00846	0.00809
50	0.00121	0.00158	0.00183	0.00819	0.00529	0.00242	0.00264	0.00089
51	0.00834	0.00666	0.07397	0.01149	0.01004	0.02733	0.00397	0.04063
52	0.00000	0.00000	0.00003	0.00124	0.00005	0.00004	0.00002	0.00003
55	0.00112	0.03414	0.01056	0.00459	0.01250	0.03298	0.20873	0.01049
60	0.01304	0.01068	0.00664	0.02514	0.01744	0.00111	0.02463	0.00743
61	0.00100	0.00015	0.00155	0.00043	0.14246	0.00535	0.00569	0.00315
62	0.00082	0.00092	0.00388	0.00044	0.00357	0.08384	0.17351	0.00970
63	0.02367	0.00976	0.01467	0.05856	0.13281	0.07092	0.09197	0.00855
64	0.00846	0.01511	0.02018	0.00508	0.01185	0.00917	0.01068	0.26540
65	0.00385	0.01896	0.01452	0.01445	0.01352	0.02599	0.03152	0.01767
66	0.00973	0.01606	0.01280	0.00637	0.00991	0.02512	0.00894	0.00243
67	0.00038	0.00145	0.00081	0.00039	0.00443	0.00336	0.00049	0.00134
70	0.00948	0.05161	0.01792	0.00531	0.01193	0.01007	0.01119	0.00794
71	-0.00252	0.00436	0.00491	0.03001	0.00535	0.05120	0.00975	0.00238
72	0.00648	0.01106	0.00796	0.02291	0.02946	0.03167	0.03507	0.01135
73	0.00088	0.00034	0.00020	0.00094	0.00163	0.00087	0.00096	0.00052
74	0.03672	0.05837	0.05862	0.03192	0.06765	0.08725	0.04456	0.03757
75	0.00085	0.00466	0.00249	0.01690	0.00157	0.00035	0.00070	0.00140
80	0.00008	0.00019	0.00180	0.00063	0.00037	0.00041	0.00281	0.00038
85	0.00034	0.00045	0.00287	0.00048	0.00087	0.00081	0.00039	0.00059
90	0.00196	0.00548	0.00564	0.00096	0.00224	0.00163	0.00160	0.00160
91	0.00002	0.00006	0.00096	0.00017	0.00004	0.00027	0.00071	0.00077
92	0.00040	0.00074	0.00631	0.00127	0.00053	0.00234	0.00646	0.00330
93	0.00009	0.00007	0.00744	0.00080	0.00271	0.00407	0.00133	0.00158
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	65	66	67	70	71	72	73	74
1 - 5	0.00000	0.00000	0.00000	0.00031	0.00001	-0.00001	0.00362	0.00008
10 - 13	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001
14	0.00000	0.00000	0.00001	0.00049	0.00000	0.00000	0.00003	0.00007
15	0.00042	0.00020	0.00119	0.00004	0.00016	0.00140	0.00407	0.00261
16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001
17	0.00003	0.00003	0.00006	0.00128	0.00021	0.00008	0.00319	0.00049
18	0.00007	0.00005	0.00018	0.00006	0.00032	0.00024	0.00414	0.00056
19	0.00004	0.00002	0.00020	0.00002	0.00010	0.00009	0.00451	0.00071
20	0.00000	0.00001	0.00016	0.00415	0.00028	0.00013	0.00093	0.00046
21	0.00022	0.00026	0.00126	0.00079	0.00055	0.00017	0.00402	0.00276
22	0.00227	0.00127	0.00354	0.00127	0.00069	0.00183	0.00428	0.01137
23&36	0.00036	0.00105	0.00108	0.00096	0.00536	0.00311	0.00648	0.00514
24	0.00000	0.00003	0.00019	0.00071	0.00020	0.00004	0.00913	0.00144
25	0.00022	0.00011	0.00049	0.00164	0.00044	0.00214	0.00306	0.00108
26	0.00000	0.00000	0.00001	0.00576	0.00000	0.00010	0.00004	0.00012
27	0.00000	0.00000	0.00004	0.00000	0.00009	0.00034	0.00022	0.00010
28	0.00006	0.00007	0.00033	0.00117	0.00029	0.00036	0.00032	0.00023
29	-0.00024	0.00007	0.00024	0.00057	0.01108	0.00183	0.00217	0.00145
30	0.00011	0.00001	0.00008	0.00207	0.00046	0.00288	0.00307	0.00056
31	0.00002	0.00006	0.00018	0.00028	0.00110	0.00424	0.00166	0.00050
32	0.00002	0.00007	0.00051	0.00027	0.00112	0.00636	0.00379	0.00056
33	0.00000	0.00001	0.00012	0.00004	0.00031	0.00205	0.00140	0.00056
34	-0.00009	0.00014	0.00034	0.00038	0.00518	0.00128	0.00104	0.00102
35	-0.00001	0.00001	0.00020	0.00006	0.00054	0.00052	0.00124	0.00056
37	0.00000	0.00000	0.00000	0.00000	0.00006	0.00000	0.00392	0.00012
40	0.00005	0.00016	0.00159	0.00133	0.00414	0.00413	0.01082	0.00697
41	0.00000	0.00000	0.00003	0.00007	0.00020	0.00013	0.00061	0.00018
45	0.00168	0.00167	0.00007	0.03152	0.00084	0.00008	0.00169	0.00316
50	0.00032	0.00096	0.00040	0.00105	0.01160	0.00250	0.00317	0.00206
51	0.00052	0.00053	0.00158	0.00355	0.00336	0.07508	0.00702	0.00707
52	0.00000	0.00000	0.00005	0.00006	0.00029	0.00003	0.00005	0.00003
55	0.00105	0.00071	0.00221	0.00157	0.00162	0.00857	0.00629	0.01527
60	0.00112	0.00098	0.00132	0.00070	0.01133	0.00411	0.00909	0.00499
61	0.00008	0.00006	0.00042	0.00001	0.00061	-0.00001	0.00000	0.00021
62	0.00276	0.00110	0.00090	0.00067	0.00304	0.00094	0.00619	0.01048
63	0.00262	0.00169	0.00486	0.00260	0.00777	0.00060	0.00928	0.01090
64	0.01077	0.03252	0.03043	0.00602	0.00957	0.03073	0.02155	0.02518
65	0.21829	0.02975	0.05947	0.10104	0.07205	0.02825	0.03269	0.02589
66	0.01039	0.45138	0.07731	0.01601	0.01240	0.01849	0.00698	0.00818
67	0.06553	0.11617	0.17350	0.00055	0.00151	0.00463	0.01588	0.00740
70	0.00432	0.00443	0.00083	0.00443	0.00314	0.00354	0.01420	0.01363
71	0.00295	0.00058	0.00096	0.00074	0.13020	0.00788	0.00605	0.00443
72	0.01488	0.00692	0.01354	0.00557	0.00817	0.18606	0.04398	0.02025
73	0.00012	0.00010	0.00011	0.00019	0.00016	0.02728	0.14892	0.00436
74	0.08384	0.03290	0.05122	0.04187	0.06313	0.29600	0.17098	0.30571
75	0.00047	0.00036	0.00068	0.00617	0.00040	0.00051	0.00153	0.00453
80	0.00007	0.00006	0.00013	0.00191	0.00004	0.00252	0.01278	0.00060
85	0.00030	0.00077	0.00035	0.00010	0.00024	0.00046	0.00498	0.00076
90	0.00008	0.00011	0.00124	0.00141	0.00222	0.00209	0.00477	0.00200
91	0.00020	0.00008	0.00008	0.00007	0.00011	0.00017	0.00038	0.00158
92	0.00066	0.00047	0.00071	0.00063	0.00103	0.00464	0.00196	0.00360
93	0.00048	0.00017	0.00046	0.00019	0.00380	0.00051	0.00702	0.00395
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	75	80	85	90	91	92	93	95
1 - 5	0.00075	0.00511	0.00132	0.00000	0.00167	0.00062	0.00001	0.00000
10 - 13	0.00282	0.00021	0.00000	0.00000	0.00000	0.00026	0.00010	0.00000
14	0.00017	0.00000	0.00000	0.00288	0.00046	0.00023	0.00013	0.00000
15	0.00328	0.00019	0.00265	0.00369	0.02959	0.00682	0.00080	0.00000
16	0.00000	0.00000	0.00000	0.00000	0.00007	0.00001	0.00000	0.00000
17	0.00072	-0.00008	0.00179	0.00066	0.00154	0.00075	0.00311	0.00000
18	0.00475	-0.00009	0.00028	0.00195	0.00374	0.00224	0.00727	0.00000
19	0.00006	-0.00010	0.00000	0.00281	0.00295	0.00161	0.00419	0.00000
20	0.00014	0.00120	0.00009	0.00048	0.00141	0.00070	0.00022	0.00000
21	0.00250	0.00868	0.00541	0.00418	0.00199	0.00085	0.00064	0.00000
22	0.00381	0.01208	0.00074	0.00964	0.00658	0.00570	0.00783	0.00000
23&36	0.01121	0.00667	0.01127	0.00760	0.00491	0.00368	0.00799	0.00000
24	0.00584	0.00345	0.07054	0.03710	0.00762	0.00794	0.01996	0.00000
25	0.00284	0.00021	0.01231	0.01110	0.00271	0.00141	0.00304	0.00000
26	0.00233	0.00009	0.00021	0.01142	0.00295	0.00222	0.00050	0.00000
27	0.00038	0.00001	0.00000	0.00147	0.00016	0.00006	0.00017	0.00000
28	0.00284	0.00308	0.00016	0.00408	0.00005	0.00047	0.00014	0.00000
29	0.00131	0.00006	0.00008	0.00271	0.00103	0.00072	0.00255	0.00000
30	0.00248	0.00380	0.00007	0.00344	0.00018	0.00265	0.00033	0.00000
31	0.00013	0.00003	0.00182	0.00167	0.00074	0.00081	0.00140	0.00000
32	0.00045	-0.00005	0.00104	0.00168	0.00178	0.00409	0.00213	0.00000
33	0.00143	0.00370	0.01909	0.00086	0.00097	0.00043	0.00012	0.00000
34	0.00051	0.00004	0.00007	0.00257	0.00039	0.00028	0.00087	0.00000
35	0.00253	0.00001	0.00015	0.00272	0.00133	0.00080	0.00064	0.00000
37	0.00000	0.00001	0.00000	0.00103	0.00000	0.00012	0.00018	0.00000
40	0.01390	0.01735	0.00219	0.01381	0.00373	0.00982	0.01278	0.00000
41	0.00009	0.00001	0.00000	0.00125	0.00894	0.00061	0.00103	0.00000
45	0.04471	0.01117	0.00053	0.01238	0.00309	0.00212	0.00118	0.00000
50	0.00229	0.00019	0.00015	0.00475	0.00255	0.00148	0.00444	0.00000
51	0.00762	0.00638	0.01696	0.01424	0.01097	0.00651	0.00763	0.00000
52	0.00000	0.00009	0.00000	0.00012	0.00010	0.00000	0.00004	0.00000
55	0.01243	0.00808	0.00492	0.00546	0.01629	0.00827	0.00467	0.00000
60	0.02033	0.00383	0.00279	0.02546	0.00297	0.00225	0.00597	0.00000
61	0.00045	0.00001	0.00000	0.00751	0.00064	0.00064	0.00020	0.00000
62	0.00332	0.00899	0.00157	0.00123	0.00483	0.00308	0.00253	0.00000
63	0.00013	0.00061	0.00000	0.01136	0.00875	0.00472	0.00765	0.00000
64	0.01868	0.00886	0.00000	0.01762	0.02452	0.00942	0.02219	0.00000
65	0.01081	0.00431	0.00053	0.02957	0.05385	0.02587	0.02746	0.00000
66	0.00268	0.00970	0.00363	0.01874	0.00245	0.00828	0.00880	0.00000
67	0.00000	0.00006	0.00000	0.00191	0.00025	0.00049	0.00216	0.00000
70	0.07361	0.00502	0.00261	0.00698	0.00469	0.02304	0.03374	0.00000
71	0.00094	0.00057	0.00000	0.02511	0.00432	0.00948	0.02244	0.00000
72	0.02536	0.00366	0.00782	0.04280	0.03246	0.00888	0.02355	0.00000
73	0.00179	0.00582	0.00384	0.01934	0.00436	0.00200	0.00046	0.00000
74	0.06415	0.02984	0.00773	0.09066	0.13080	0.06297	0.09064	0.00000
75	0.00501	0.00011	0.00086	0.00101	0.00280	0.00330	0.00656	0.00000
80	0.00340	0.03311	0.00831	0.00246	0.00185	0.00079	0.00050	0.00000
85	0.00042	0.00054	0.17387	0.00359	0.00219	0.00087	0.00538	0.00000
90	0.00401	0.00119	0.00137	0.25365	0.00266	0.00324	0.00833	0.00000
91	0.00002	0.00002	0.00010	0.00025	0.07292	0.01142	0.00129	0.00000
92	0.00664	0.02081	0.00001	0.00543	0.08533	0.08747	0.00510	0.00000
93	0.00087	0.00703	0.00110	0.02279	0.01216	0.00477	0.06293	0.00000
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

APPENDIX VI: Leontief Inverse Matrix

	Product	1-5	10-13	14	15	16
1 - 5	Agriculture, forestry and fishing	1.35820	0.00378	0.00804	0.39840	0.17300
10 - 13	Coal, peat, petroleum and metal ore extraction	0.03508	1.22638	0.09664	0.02629	0.01001
14	Other mining and quarrying	0.00821	0.00796	1.23077	0.00303	0.00127
15	Manufacture of food and beverages	0.19616	0.00606	0.01426	1.20028	0.03348
16	Tobacco products	0.00001	0.00001	0.00001	0.00001	1.01321
17	Textiles	0.00485	0.00154	0.00246	0.00260	0.00145
18	Wearing apparel	0.00096	0.00137	0.00244	0.00075	0.00038
19	Leather and leather products	0.00059	0.00045	0.00058	0.00061	0.00031
20	Wood and wood products (excl furniture)	0.00578	0.00720	0.01081	0.00601	0.00980
21	Pulp, paper and paper products	0.01156	0.00331	-0.00106	0.03889	0.04856
22	Printed matter and recorded media	0.00666	0.00437	0.00419	0.00793	0.00361
23&36	Petroleum and other manufacturing products	0.05319	0.04066	0.13663	0.03717	0.01454
24	Chemical products and man-made fibres	0.11350	0.03468	0.01905	0.04036	0.02122
25	Rubber and plastics	0.01049	0.01491	0.01207	0.02190	0.00424
26	Other non-metallic mineral products	0.00533	0.00913	0.05340	0.00617	0.00153
27	Basic metals	0.01329	0.02009	-0.00487	0.01208	0.00418
28	Fabricated metal products	0.02655	0.02681	0.01395	0.01773	0.00793
29	Machinery and equipment n.e.c.	0.02430	0.03086	0.00387	0.01274	0.00688
30	Office machinery and computers	0.00415	0.00196	0.00293	0.00309	0.00153
31	Electrical machinery and apparatus n.e.c.	0.00364	0.00409	0.00700	0.00298	0.00193
32	Radio, television and communications apparatus	0.00492	0.00501	0.00819	0.00593	0.00479
33	Medical, precision and optical instruments	0.00165	0.00166	0.00176	0.00110	0.00070
34	Motor vehicles and trailers	0.00121	0.00193	0.00422	0.00129	0.00056
35	Other transport equipment	0.00825	0.00144	0.00651	0.00385	0.00230
37	Recycling	0.00106	0.00115	0.00006	0.00168	0.00072
40	Electricity and gas	0.03515	0.06405	0.06101	0.03456	0.01358
41	Water collection and distribution	0.00171	0.00108	0.00077	0.00156	0.00085
45	Construction work	0.02537	0.04369	0.05283	0.01337	0.00666
50	Motor fuel and vehicle trade and repair	0.00767	0.01391	0.01724	0.00510	0.00226
51	Wholesale trade	0.10019	0.04889	0.08424	0.11344	0.03425
52	Retail trade and repair of household goods	0.00006	0.00010	0.00045	0.00008	0.00003
55	Hotel and restaurant services	0.01853	0.01307	0.03647	0.02590	0.02640
60	Land transport services	0.01801	0.06294	0.31601	0.03810	0.01420
61	Water transport services	0.00199	0.00141	0.00609	0.00159	0.00099
62	Air transport services	0.00864	0.01115	0.06368	0.01675	0.01961
63	Auxiliary transport services and travel agencies	0.00989	0.01100	0.03456	0.01461	0.00939
64	Post and telecommunication services	0.02592	0.02222	0.03666	0.03449	0.03068
65	Financial intermediation services	0.07460	0.10652	0.10733	0.08337	0.04402
66	Insurance and pension services	0.05905	0.06103	0.07586	0.04359	0.06220
67	Services auxiliary to financial intermediation	0.01776	0.02698	0.02765	0.02090	0.01601
70	Real estate services	0.00954	0.00983	0.01094	0.01149	0.00831
71	Renting services of machinery and equipment	0.00759	0.01179	0.12707	0.00949	0.00454
72	Computer and related services	0.01779	0.04901	0.04772	0.02484	0.03518
73	Research and development services	0.01267	0.00810	0.00381	0.00288	0.00457
74	Other business services	0.17997	0.22181	0.12496	0.42733	0.12367
75	Public administration and defence	0.01045	0.00493	0.00916	0.00656	0.00356
80	Education	0.00078	0.00061	0.00083	0.00078	0.00067
85	Health and social work services	0.02238	0.00105	0.00138	0.00805	0.00508
90	Sewage and refuse disposal services	0.00468	0.00578	0.00570	0.00726	0.00829
91	Membership organisation services n.e.c.	0.00323	0.00056	0.00057	0.00184	0.00168
92	Recreation	0.00340	0.00232	0.00394	0.00427	0.00221
93	Other services	0.00381	0.01135	0.01315	0.00519	0.00211
95	Private households with employed persons	0.00000	0.00000	0.00000	0.00000	0.00000

[&]Leontief Inverse Matrix = $(I-A)^{-1}$ where I is the Identity matrix

	17	18	19	20	21	22	23, 36	24
1 - 5	0.00787	0.00782	0.01322	0.20373	0.00748	0.00463	0.01793	0.00672
10 - 13	0.00637	0.01665	0.00738	0.02477	0.01628	0.00885	0.62140	0.01055
14	0.00011	0.00087	0.00063	0.00257	0.00067	0.00048	0.00611	0.00137
15	0.01688	0.01215	0.02035	0.03636	0.01512	0.00910	0.01170	0.01396
16	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
17	1.98907	0.38416	0.35965	0.00533	0.00957	0.00358	0.00805	0.00284
18	-0.06842	1.40063	-0.01162	0.00047	0.00029	0.00101	0.00094	0.00138
19	0.00104	0.00048	1.19662	0.00049	0.00048	0.00108	0.00038	0.00144
20	-0.00628	0.00334	-0.00020	1.28287	0.00818	0.00215	0.08754	0.00217
21	0.03329	0.02612	0.02140	0.01644	1.54217	0.02940	0.01921	0.01123
22	0.00655	0.00509	0.00488	0.00515	0.02688	1.04415	0.00503	0.01034
23&36	0.04234	0.01607	0.01758	0.03426	0.02035	0.01345	1.22044	0.01408
24	0.36101	0.08284	0.06932	0.08208	0.08247	0.01491	0.03066	1.14780
25	0.01846	0.00762	0.00163	0.01298	0.03841	0.00504	0.03553	0.00697
26	0.00524	0.00215	0.00249	0.00474	0.00226	0.00233	0.03206	0.00194
27	-0.02808	0.00555	0.00364	0.03241	0.01334	0.00283	0.02013	0.00359
28	0.01485	0.01701	0.02619	0.05265	0.01804	0.00293	0.04051	0.00436
29	0.01838	0.00782	0.01302	0.02540	0.01194	0.00404	0.01889	0.00682
30	0.00458	0.00181	0.00270	0.00222	0.00343	0.00177	-0.00039	0.00326
31	0.00341	0.00239	0.00335	0.00300	0.00250	0.00194	0.00506	0.00292
32	0.00770	0.00573	0.00803	0.00497	0.00540	0.00605	0.00524	0.00711
33	0.00105	0.00084	0.00099	0.00087	0.00081	0.00091	0.00103	0.00155
34	0.00111	0.00116	0.00119	0.00121	0.00101	0.00100	0.00151	0.00124
35	0.00202	0.00218	0.00182	0.00234	0.00162	0.00176	0.00181	0.00192
37	-0.00063	0.00152	0.00068	0.00706	0.01287	0.00085	0.00183	0.00083
40	0.04645	0.02531	0.02021	0.05489	0.03489	0.01154	0.05104	0.01808
41	0.00661	0.00269	0.00157	0.00390	0.00397	0.00177	0.00182	0.00151
45	0.00762	0.00839	0.00737	0.02714	0.00879	0.00621	0.02857	0.00659
50	0.00393	0.00314	0.00290	0.00461	0.00359	0.00262	0.00934	0.00289
51	0.08949	0.06476	0.06404	0.08193	0.05368	0.32741	0.07789	0.03661
52	0.00008	0.00006	0.00011	0.00009	0.00008	0.00005	0.00008	0.00005
55	0.03092	0.02858	0.05075	0.02076	0.03197	0.01867	0.02411	0.02023
60	0.04600	0.02920	0.06320	0.05657	0.05181	0.01431	0.05232	0.00925
61	0.00149	0.00105	0.00163	0.00154	0.00135	0.00110	0.00141	0.00074
62	0.02003	0.01036	0.01094	0.00703	0.01519	0.01830	0.01694	0.01761
63	0.01322	0.01059	0.01378	0.01084	0.01170	0.01924	0.01246	0.01380
64	0.04478	0.03540	0.04882	0.02859	0.03141	0.03910	0.02858	0.03617
65	0.08210	0.06180	0.08133	0.04294	0.05275	0.04806	0.08644	0.05577
66	0.06875	0.07600	0.12965	0.04685	0.07070	0.03218	0.06685	0.03225
67	0.02498	0.02187	0.03255	0.01391	0.01952	0.01608	0.02455	0.01911
70	0.01140	0.00834	0.01285	0.00787	0.00974	0.01373	0.00950	0.01379
71	0.00985	0.01162	0.01032	0.01168	0.01014	0.00575	0.01088	0.00777
72	0.04526	0.02330	0.06789	0.02416	0.03429	0.02576	0.04463	0.05352
73	0.03946	0.01259	0.02062	0.01363	0.01275	0.09581	0.00718	0.10704
74	0.27911	0.25316	0.23223	0.17151	0.20050	0.47522	0.22754	0.67618
75	0.00701	0.00822	0.01149	0.00596	0.00414	0.00344	0.00600	0.00422
80	0.00137	0.00093	0.00109	0.00068	0.00081	0.00190	0.00073	0.00236
85	0.00383	0.00356	0.00207	0.00448	0.00263	0.00193	0.00224	0.00381
90	0.01750	0.02296	0.04676	0.01636	0.00492	0.00391	0.00647	0.00447
91	0.00078	0.00086	0.00072	0.00088	0.00097	0.00113	0.00077	0.00142
92	0.00647	0.00544	0.00539	0.00238	0.00415	0.00354	0.00307	0.00449
93	0.01033	0.00632	0.01306	0.00600	0.01268	0.00385	0.00943	0.00475
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	25	26	27	28	29	30	31	32
1 - 5	0.00933	0.00520	0.00477	0.00374	0.00431	0.00657	0.00688	0.00361
10 - 13	0.04148	0.05660	0.32724	0.10120	0.05111	0.01318	0.01870	0.01560
14	0.00246	0.05952	0.01964	0.00664	0.00352	0.00070	0.00164	0.00088
15	0.01447	0.00869	0.00696	0.00701	0.00807	0.01317	0.01247	0.00640
16	0.00001	0.00001	0.00000	0.00000	0.00001	0.00002	0.00001	0.00001
17	0.00094	0.00160	0.00174	0.00090	0.00067	0.00213	0.00169	0.00161
18	0.00091	0.00043	0.00069	0.00050	0.00049	0.00089	0.00080	0.00074
19	0.00048	0.00034	0.00045	0.00040	0.00039	0.00100	0.00075	0.00104
20	0.02404	0.00907	0.01108	0.00599	0.00348	0.00252	0.00337	0.00362
21	0.01252	0.02456	0.00788	0.00819	0.00702	0.00773	0.00538	0.01009
22	0.00454	0.00432	0.00391	0.00327	0.00378	0.01186	0.00783	0.00562
23&36	0.05008	0.05431	0.12895	0.04723	0.02763	0.01720	0.02387	0.01636
24	0.09707	0.03120	0.05676	0.02719	0.01507	0.01941	0.01834	0.06117
25	1.25745	0.01391	0.00917	0.01328	0.02196	0.00667	0.01733	0.01117
26	0.02209	1.18148	0.00679	0.01200	0.00722	0.00265	0.00502	0.00425
27	0.05435	0.04594	1.18334	0.36290	0.16000	0.00946	0.01357	0.01632
28	0.06545	0.02940	0.03571	1.10503	0.15464	0.01349	0.01596	0.02546
29	0.03649	0.02351	0.01955	0.04051	1.14961	0.01236	0.00973	0.03911
30	0.00215	0.00175	0.00209	0.00183	-0.00363	1.83300	0.09127	0.09790
31	-0.00342	0.00245	0.00098	-0.00056	0.01918	0.06416	1.39255	0.08037
32	0.00501	0.00616	0.00398	0.00129	0.00830	0.13844	0.13486	1.43902
33	-0.00113	0.00078	0.00098	0.00046	0.00083	0.00327	0.00040	0.01969
34	0.00114	0.00135	0.00126	0.00049	0.00059	0.00161	0.00135	0.00067
35	0.00165	0.00220	0.00170	0.00044	0.00164	0.00232	0.00226	0.00182
37	0.00295	0.00238	0.04902	0.02190	0.00773	0.00074	0.00091	0.00123
40	0.05093	0.06977	0.08257	0.03946	0.02951	0.01642	0.02649	0.03323
41	0.00184	0.00135	0.00919	0.00355	0.00471	0.00060	0.00058	0.00082
45	0.00768	0.00818	0.01845	0.01116	0.00746	0.00837	0.02385	0.01116
50	0.00476	0.00547	0.01168	0.00561	0.00345	0.00371	0.00878	0.00421
51	0.06877	0.08300	0.07623	0.06716	0.06877	0.27548	0.12287	0.11881
52	0.00007	0.00009	0.00006	0.00006	0.00005	0.00007	0.00007	0.00003
55	0.02874	0.02086	0.01548	0.01706	0.01986	0.02893	0.02804	0.01372
60	0.04483	0.05942	0.03545	0.03111	0.02637	0.02552	0.02554	0.01078
61	0.00135	0.00166	0.00130	0.00116	0.00089	0.00135	0.00109	0.00087
62	0.01568	0.02699	0.01999	0.01434	0.01193	0.02129	0.03188	0.02424
63	0.01251	0.01318	0.01011	0.00900	0.00872	0.02237	0.01909	0.01977
64	0.04294	0.03949	0.02251	0.02438	0.02839	0.03802	0.04360	0.01823
65	0.03600	0.08514	0.08375	0.08047	0.07623	0.05523	0.05732	0.03181
66	0.06571	0.04622	0.05406	0.04485	0.05101	0.03185	0.04932	0.02792
67	0.01606	0.02112	0.02200	0.01997	0.02047	0.01756	0.01960	0.01097
70	0.00929	0.00693	0.00729	0.00630	0.00628	0.01587	0.01339	0.00681
71	0.01133	0.02327	0.01027	0.01631	0.00859	0.00854	0.01169	0.00680
72	0.03241	0.02474	0.02695	0.02260	0.02270	0.03955	0.11032	0.03276
73	0.01474	0.00708	0.00888	0.00752	0.02281	0.02057	0.02211	0.06451
74	0.20606	0.15982	0.14659	0.11520	0.17281	0.71562	0.53644	0.18116
75	0.00435	0.00432	0.00568	0.00516	0.00360	0.00512	0.00545	0.00264
80	0.00088	0.00056	0.00065	0.00059	0.00082	0.00136	0.00148	0.00187
85	0.00304	0.00162	0.00158	0.00199	0.00260	0.00313	0.00379	0.00478
90	0.00870	0.00579	0.02747	0.02853	0.00808	0.00443	0.00447	0.00317
91	0.00101	0.00049	0.00046	0.00047	0.00068	0.00149	0.00147	0.00059
92	0.00275	0.00334	0.00269	0.00220	0.00252	0.00581	0.00492	0.00342
93	0.00694	0.00698	0.00599	0.00677	0.00490	0.00448	0.00558	0.00278
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	33	34	35	37	40	41	45	50
1 - 5	0.00213	0.00523	0.00320	0.00344	0.00576	0.00708	0.01350	0.00331
10 - 13	-0.00783	0.04601	0.03644	0.15892	0.30487	0.03941	**0.03157**	0.01639
14	0.00063	0.00266	0.00209	0.00916	0.00280	0.00282	0.02463	0.00058
15	0.00539	0.01028	0.00632	0.00558	0.00740	0.01429	0.00803	0.00639
16	0.00001	0.00001	0.00000	0.00000	0.00000	0.00001	0.00001	0.00001
17	-0.00248	0.00147	0.00029	0.00133	0.00201	0.00223	0.00832	0.00634
18	0.00114	0.00055	0.00000	0.00060	0.00056	0.00089	0.00146	0.00039
19	0.00059	0.00066	0.00005	0.00041	0.00030	0.00086	0.00107	0.00628
20	0.00088	0.00399	0.00227	0.00635	0.01793	0.00695	0.04522	0.00272
21	0.01062	0.00693	0.00188	0.00765	0.00702	0.01368	0.00864	0.00334
22	0.00486	0.00456	0.00233	0.00373	0.00795	0.02314	0.01045	0.00560
23&36	0.00826	0.02890	0.01989	0.07314	0.24935	0.04139	**0.03830**	0.02427
24	0.05593	0.03333	0.01104	0.03669	0.01569	0.03893	0.03032	0.00741
25	0.05323	0.03714	0.01126	0.00663	0.01113	0.02074	0.04620	0.01529
26	0.00214	0.00407	0.00246	0.00407	0.00900	0.01144	0.08823	0.00347
27	0.02446	0.12984	0.09648	0.53910	0.01358	0.02256	0.04079	0.00860
28	0.01903	0.04906	0.00814	0.02547	0.02624	0.02209	0.06725	0.00886
29	0.01826	0.02681	0.00035	0.01701	0.01872	0.05491	0.02973	0.01102
30	0.01655	0.03992	0.00823	0.00183	0.01323	0.01066	0.01111	0.00282
31	0.04544	0.09017	0.10175	0.00208	0.01418	0.00819	0.04282	0.00587
32	0.03454	0.34155	0.01254	0.00434	0.00770	0.01533	0.01266	0.01694
33	1.28397	0.00586	0.01907	0.00080	0.00248	0.01022	0.00441	0.00164
34	0.00063	1.05579	-0.00181	0.00150	0.00120	0.00331	0.00232	0.03243
35	0.00106	0.00505	1.35849	0.00184	0.00091	0.00171	0.00292	0.00228
37	0.00140	0.00626	0.00409	1.08202	0.00096	0.00146	0.00314	0.00052
40	0.01677	0.03151	0.02927	0.05747	1.32731	0.10452	**0.02386**	0.01798
41	0.00186	0.01598	0.00177	0.00463	0.00070	1.01514	0.00169	0.00115
45	0.00421	0.01034	0.01896	0.01151	0.02451	0.09457	1.36282	0.00540
50	0.00192	0.02109	0.00344	0.00715	0.00465	0.00985	0.00522	1.02046
51	0.09773	0.10760	0.04072	0.08307	0.07396	0.06048	0.07378	0.02272
52	0.00003	0.00005	0.00001	0.00014	0.00004	0.00019	0.00005	0.00004
55	0.01885	0.02541	0.01687	0.01202	0.01129	0.02444	0.01445	0.01381
60	0.01010	0.02221	0.00873	0.09737	0.02262	0.01652	0.02327	0.02159
61	0.00059	0.00113	0.00057	0.00202	0.00079	0.00125	0.00093	0.00281
62	0.01208	0.02564	0.01321	0.01264	0.00768	0.01138	0.00972	0.01100
63	0.01008	0.01395	0.00769	0.01335	0.00774	0.01755	0.00878	0.02265
64	0.02527	0.03074	0.01278	0.02178	0.01966	0.04971	0.02059	0.03686
65	0.02576	0.06170	0.01526	0.08040	0.09658	0.07249	0.04840	0.04815
66	0.03590	0.05841	0.04807	0.09714	0.03089	0.06590	0.02625	0.05631
67	0.01081	0.01938	0.01127	0.02723	0.02104	0.02151	0.01191	0.01424
70	0.00701	0.00836	0.00440	0.01017	0.00628	0.02740	0.02893	0.02419
71	0.00446	0.00783	-0.04062	0.01183	0.00932	0.02596	0.02971	0.00887
72	0.02831	0.03374	0.01572	0.05076	0.03199	0.05975	0.02398	0.02702
73	0.03450	0.02415	0.00390	0.00736	0.00537	0.01886	0.00796	0.00422
74	0.23786	0.17777	0.12352	0.14444	0.15623	0.38264	0.15861	0.12807
75	0.00257	0.00420	0.00322	0.00809	0.00343	0.00492	0.01094	0.00534
80	0.00090	0.00107	0.00053	0.00065	0.00056	0.00328	0.00066	0.00055
85	0.00249	0.00276	0.00247	0.00121	0.00193	0.00374	0.00196	0.00140
90	0.00322	0.00892	0.00521	0.01381	0.01113	0.05432	0.01362	0.00808
91	0.00074	0.00085	0.00072	0.00044	0.00045	0.00293	0.00049	0.00040
92	0.00340	0.00268	0.00431	0.00229	0.00190	0.00442	0.00212	0.00214
93	0.00253	0.00435	0.00314	0.01175	0.00481	0.00486	0.00318	0.00216
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	51	52	55	60	61	62	63	64
1 - 5	0.00226	0.01285	0.15311	0.00566	0.02010	0.01375	0.04081	0.00608
10 - 13	0.00821	0.01326	0.02303	0.04744	0.03901	0.07883	0.03347	0.01265
14	0.00045	0.00066	0.00191	0.00100	0.00105	0.00128	0.00224	0.00093
15	0.00475	0.02805	0.35199	0.01088	0.03038	0.02879	0.09301	0.01322
16	0.00000	0.00001	0.00020	0.00001	0.00001	0.00002	0.00005	0.00001
17	0.00118	0.00653	0.00770	0.00180	0.00193	0.00339	0.00351	0.00215
18	0.00019	0.00040	0.00303	0.00081	0.00063	0.00120	0.00141	0.00112
19	0.00042	0.00137	0.00233	0.00065	0.00058	0.00090	0.00105	0.00086
20	0.00143	0.00277	0.00594	0.00706	0.00613	0.01152	0.00633	0.00362
21	0.00225	0.00516	0.01732	0.00464	0.00405	0.00566	0.00758	0.00421
22	0.00408	0.00512	0.00931	0.00438	0.00539	0.00638	0.01028	0.00664
23&36	0.01400	0.01781	0.03301	0.08780	0.06943	0.14925	0.05826	0.01778
24	0.00252	0.00813	0.02284	0.00634	0.00713	0.00881	0.01104	0.01255
25	0.00434	0.00625	0.01063	0.01505	0.00791	0.00873	0.00960	0.02323
26	0.00228	0.00280	0.00442	0.00428	0.00351	0.00588	0.00475	0.00527
27	0.00125	0.00318	0.00563	0.00757	0.00910	0.00811	0.00541	0.00763
28	0.00160	0.00405	0.00866	0.00799	0.00760	0.00754	0.00648	0.00825
29	0.00129	0.00493	0.00636	0.00554	0.00436	0.00567	0.00497	0.01063
30	0.00069	0.00165	0.00261	0.00250	0.00352	0.00299	0.00297	0.01737
31	0.00137	0.00315	0.00325	0.00872	0.00937	0.00837	0.00564	0.03392
32	0.00325	0.00576	0.00810	0.00824	0.00794	0.00888	0.01008	0.17114
33	0.00046	0.00065	0.00123	0.00087	0.00204	0.00255	0.00200	0.00859
34	0.00070	0.00157	0.00149	0.00937	0.00139	0.00160	0.00230	0.00164
35	0.00098	0.00100	0.00309	0.00984	0.07211	0.05424	0.01794	0.00343
37	0.00012	0.00028	0.00073	0.00050	0.00077	0.00061	0.00054	0.00070
40	0.00700	0.02701	0.03761	0.01334	0.01669	0.01782	0.02301	0.01698
41	0.00036	0.00080	0.00137	0.00056	0.00063	0.00075	0.00090	0.00055
45	0.00317	0.00996	0.01271	0.00745	0.00960	0.00988	0.02069	0.01975
50	0.00198	0.00298	0.00486	0.01089	0.00924	0.00647	0.00678	0.00318
51	1.01594	0.02334	0.12321	0.03106	0.04046	0.06189	0.05888	0.08595
52	0.00003	1.00004	0.00008	0.00131	0.00013	0.00011	0.00011	0.00008
55	0.01005	0.04270	1.02821	0.02583	0.06232	0.06678	0.25501	0.02565
60	0.01648	0.01636	0.02406	1.03550	0.03383	0.01614	0.04083	0.01763
61	0.00162	0.00077	0.00302	0.00149	1.16822	0.00831	0.00996	0.00571
62	0.00828	0.00751	0.01690	0.01802	0.04475	1.11682	0.22164	0.02456
63	0.03007	0.01673	0.02820	0.07249	0.18301	0.09760	1.13329	0.02348
64	0.01839	0.03380	0.05045	0.02119	0.04162	0.03965	0.04741	1.37593
65	0.01574	0.04930	0.06426	0.04480	0.05822	0.08139	0.09278	0.05237
66	0.02421	0.04273	0.04996	0.02895	0.04749	0.07980	0.05651	0.02286
67	0.00623	0.01377	0.01754	0.01044	0.02123	0.02643	0.02092	0.01215
70	0.01227	0.05702	0.02713	0.01205	0.02375	0.02085	0.02702	0.01695
71	-0.00042	0.00865	0.01215	0.03973	0.01438	0.06989	0.03225	0.00882
72	0.01449	0.02436	0.02851	0.04344	0.06654	0.06625	0.07625	0.03480
73	0.00285	0.00371	0.00493	0.00497	0.00761	0.00689	0.00777	0.01191
74	0.07955	0.14219	0.26255	0.12117	0.22243	0.25772	0.24076	0.15770
75	0.00183	0.00657	0.00625	0.01900	0.00474	0.00331	0.00459	0.00385
80	0.00039	0.00076	0.00259	0.00135	0.00173	0.00149	0.00454	0.00122
85	0.00074	0.00138	0.00704	0.00135	0.00269	0.00253	0.00316	0.00223
90	0.00349	0.00931	0.01172	0.00357	0.00683	0.00601	0.00768	0.00518
91	0.00025	0.00050	0.00212	0.00062	0.00088	0.00116	0.00199	0.00163
92	0.00139	0.00249	0.00992	0.00352	0.00463	0.00638	0.01281	0.00693
93	0.00095	0.00187	0.01118	0.00298	0.00652	0.00855	0.00712	0.00422
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	65	66	67	70	71	72	73	74
1 - 5	0.00197	0.00221	0.00257	0.00292	0.00221	0.00650	0.01280	0.00741
10 - 13	0.00327	0.00477	0.00438	0.00439	0.00970	0.01252	0.01709	0.01305
14	0.00020	0.00028	0.00021	0.00188	0.00031	0.00052	0.00070	0.00064
15	0.00452	0.00495	0.00606	0.00311	0.00454	0.01445	0.01680	0.01670
16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	0.00001	0.00003
17	0.00074	0.00087	0.00091	0.00326	0.00138	0.00246	0.01280	0.00316
18	0.00042	0.00048	0.00059	0.00025	0.00082	0.00143	0.00722	0.00156
19	0.00034	0.00037	0.00054	0.00022	0.00048	0.00115	0.00700	0.00159
20	0.00084	0.00122	0.00111	0.00738	0.00187	0.00260	0.00415	0.00307
21	0.00216	0.00281	0.00398	0.00273	0.00263	0.00527	0.01178	0.00863
22	0.00632	0.00625	0.00743	0.00367	0.00369	0.01149	0.01198	0.01946
23&36	0.00518	0.00765	0.00657	0.00600	0.01475	0.01860	0.02450	0.01981
24	0.00177	0.00261	0.00255	0.00418	0.00304	0.00650	0.02151	0.00709
25	0.00204	0.00328	0.00298	0.00473	0.00321	0.00819	0.00923	0.00545
26	0.00077	0.00117	0.00077	0.01016	0.00110	0.00207	0.00224	0.00212
27	0.00083	0.00141	0.00131	0.00282	0.00428	0.00389	0.00621	0.00288
28	0.00110	0.00181	0.00174	0.00472	0.00414	0.00410	0.00481	0.00341
29	0.00083	0.00183	0.00168	0.00262	0.01618	0.00630	0.00665	0.00465
30	0.00137	0.00200	0.00172	0.00488	0.00237	0.01054	0.00991	0.00350
31	0.00167	0.00354	0.00275	0.00280	0.00425	0.01212	0.00713	0.00420
32	0.00533	0.01416	0.01045	0.00396	0.00855	0.02548	0.01739	0.01084
33	0.00056	0.00104	0.00092	0.00051	0.00100	0.00477	0.00363	0.00190
34	0.00037	0.00086	0.00088	0.00076	0.00719	0.00301	0.00247	0.00219
35	0.00081	0.00094	0.00109	0.00063	0.00189	0.00263	0.00390	0.00288
37	0.00011	0.00016	0.00015	0.00025	0.00036	0.00055	0.00541	0.00050
40	0.00378	0.00488	0.00619	0.00554	0.01068	0.01822	0.02704	0.01882
41	0.00013	0.00017	0.00018	0.00025	0.00054	0.00060	0.00120	0.00058
45	0.00537	0.00772	0.00330	0.04540	0.00427	0.00709	0.00937	0.01078
50	0.00140	0.00288	0.00156	0.00190	0.01479	0.00595	0.00623	0.00444
51	0.01121	0.01538	0.01461	0.01329	0.01505	0.11830	0.03708	0.03289
52	0.00003	0.00004	0.00008	0.00007	0.00036	0.00009	0.00011	0.00008
55	0.00805	0.00893	0.00966	0.00625	0.00974	0.02743	0.02330	0.03229
60	0.00447	0.00584	0.00518	0.00442	0.01744	0.01497	0.02008	0.01305
61	0.00054	0.00091	0.00114	0.00031	0.00130	0.00102	0.00093	0.00117
62	0.00886	0.00829	0.00700	0.00457	0.01014	0.01452	0.01976	0.02428
63	0.00892	0.01019	0.01167	0.00632	0.01574	0.01654	0.02324	0.02430
64	0.03546	0.10401	0.06950	0.01899	0.02816	0.08528	0.06173	0.06247
65	1.30261	0.10584	0.11377	0.14197	0.12259	0.08617	0.08695	0.06985
66	0.04721	1.87022	0.18425	0.03982	0.03914	0.06700	0.04171	0.03721
67	0.11218	0.27328	1.24672	0.01891	0.01933	0.03037	0.04040	0.02556
70	0.01005	0.01324	0.00610	1.00889	0.00844	0.01817	0.02675	0.02517
71	0.00711	0.00454	0.00424	0.00395	1.15333	0.01776	0.01511	0.01195
72	0.03363	0.03041	0.03159	0.01557	0.02278	1.25663	0.08509	0.04738
73	0.00335	0.00361	0.00349	0.00243	0.00325	0.04675	1.18426	0.01253
74	0.19770	0.15664	0.14775	0.10596	0.15488	0.61182	0.39940	1.51982
75	0.00198	0.00220	0.00207	0.00740	0.00198	0.00463	0.00507	0.00801
80	0.00048	0.00055	0.00055	0.00225	0.00042	0.00458	0.01651	0.00156
85	0.00097	0.00236	0.00117	0.00056	0.00091	0.00227	0.00842	0.00214
90	0.00146	0.00200	0.00324	0.00321	0.00485	0.00715	0.01099	0.00582
91	0.00073	0.00064	0.00053	0.00037	0.00055	0.00161	0.00146	0.00288
92	0.00246	0.00276	0.00250	0.00176	0.00272	0.01027	0.00622	0.00765
93	0.00198	0.00177	0.00188	0.00122	0.00604	0.00485	0.01218	0.00773
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	75	80	85	90	91	92	93	95
1 - 5	0.00674	0.01020	0.00595	0.00799	0.02165	0.00734	0.00378	0.00000
10 - 13	0.02107	0.01358	0.01223	0.02480	0.01254	0.01006	0.01474	0.00000
14	0.00197	0.00060	0.00039	0.00678	0.00146	0.00086	0.00071	0.00000
15	0.01214	0.00668	0.00889	0.01746	0.05212	0.01614	0.00793	0.00000
16	0.00001	0.00001	0.00000	0.00001	0.00008	0.00001	0.00001	0.00000
17	0.00469	0.00067	0.00510	0.00645	0.00780	0.00413	0.01230	0.00000
18	0.00706	0.00028	0.00063	0.00474	0.00655	0.00382	0.01109	0.00000
19	0.00045	0.00018	0.00027	0.00547	0.00462	0.00247	0.00579	0.00000
20	0.00491	0.00372	0.00234	0.00524	0.00442	0.00263	0.00265	0.00000
21	0.00676	0.01563	0.01265	0.01404	0.00831	0.00389	0.00424	0.00000
22	0.00746	0.01514	0.00312	0.02011	0.01359	0.00946	0.01269	0.00000
23&36	0.02607	0.01812	0.02193	0.03419	0.01901	0.01330	0.02136	0.00000
24	0.01278	0.00849	0.10378	0.06749	0.01849	0.01434	0.03119	0.00000
25	0.00891	0.00304	0.02208	0.02526	0.00846	0.00440	0.00760	0.00000
26	0.00882	0.00214	0.00170	0.02221	0.00614	0.00437	0.00264	0.00000
27	0.00580	0.00298	0.00256	0.01148	0.00343	0.00219	0.00296	0.00000
28	0.00922	0.00620	0.00338	0.01329	0.00409	0.00299	0.00364	0.00000
29	0.00521	0.00210	0.00258	0.01011	0.00509	0.00305	0.00605	0.00000
30	0.00690	0.00840	0.00164	0.01216	0.00341	0.00708	0.00299	0.00000
31	0.00483	0.00221	0.00498	0.00900	0.00477	0.00355	0.00508	0.00000
32	0.00773	0.00399	0.00458	0.01610	0.01289	0.01130	0.01143	0.00000
33	0.00275	0.00535	0.03002	0.00311	0.00263	0.00126	0.00121	0.00000
34	0.00138	0.00039	0.00042	0.00538	0.00143	0.00088	0.00195	0.00000
35	0.00461	0.00102	0.00082	0.00772	0.00375	0.00215	0.00214	0.00000
37	0.00048	0.00040	0.00033	0.00244	0.00042	0.00037	0.00050	0.00000
40	0.02543	0.02783	0.00895	0.03808	0.01682	0.01930	0.02486	0.00000
41	0.00044	0.00025	0.00033	0.00240	0.01026	0.00102	0.00147	0.00000
45	0.06775	0.01828	0.00325	0.02965	0.01116	0.00740	0.00774	0.00000
50	0.00404	0.00115	0.00110	0.01012	0.00510	0.00293	0.00671	0.00000
51	0.02829	0.02177	0.03353	0.05636	0.04014	0.02244	0.02828	0.00000
52	0.00005	0.00011	0.00002	0.00026	0.00015	0.00003	0.00009	0.00000
55	0.01996	0.01319	0.01098	0.02579	0.03224	0.01645	0.01540	0.00000
60	0.02727	0.00791	0.00782	0.04831	0.01211	0.00730	0.01320	0.00000
61	0.00107	0.00039	0.00028	0.01277	0.00173	0.00130	0.00097	0.00000
62	0.00895	0.01344	0.00578	0.01627	0.01636	0.00926	0.01082	0.00000
63	0.00719	0.00505	0.00398	0.03210	0.02062	0.01117	0.01638	0.00000
64	0.03914	0.02081	0.00890	0.06292	0.05992	0.02673	0.04948	0.00000
65	0.04315	0.01990	0.01371	0.09663	0.10836	0.05741	0.06706	0.00000
66	0.02007	0.02680	0.01773	0.07467	0.02728	0.02845	0.03450	0.00000
67	0.00885	0.00700	0.00541	0.02707	0.01710	0.01140	0.01609	0.00000
70	0.08034	0.00915	0.00640	0.02139	0.01659	0.03026	0.04289	0.00000
71	0.00638	0.00388	0.00220	0.04829	0.01262	0.01525	0.03204	0.00000
72	0.04323	0.01220	0.02127	0.09712	0.06284	0.02293	0.04593	0.00000
73	0.00703	0.01054	0.01711	0.04453	0.01322	0.00710	0.00826	0.00000
74	0.16456	0.08929	0.10474	0.34333	0.31935	0.15923	0.22428	0.00000
75	1.00772	0.00131	0.00210	0.00532	0.00609	0.00521	0.00921	0.00000
80	0.00418	1.03461	0.01087	0.00491	0.00302	0.00140	0.00129	0.00000
85	0.00130	0.00134	1.21124	0.00763	0.00439	0.00190	0.00780	0.00000
90	0.00796	0.00315	0.00349	1.34452	0.00781	0.00654	0.01444	0.00000
91	0.00055	0.00058	0.00041	0.00138	1.08074	0.01392	0.00212	0.00000
92	0.00909	0.02457	0.00128	0.01166	0.10392	1.09861	0.00825	0.00000
93	0.00283	0.00903	0.00274	0.03626	0.01732	0.00731	1.06952	0.00000
95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000

APPENDIX VII

Bill of Quantities: Apartment Building 1

Description	Expenditure [€]	Quantity	Unit
SUBSTRUCTURE			
Excavation:	5,978.72		
Provitional: Electrical Cables, etc	487.80		
Excavation	3,220.02		
Disposal	14,655.68		
Groundwork	20,125.56		
Concrete Work:			
In-situ concrete Grade C15	15,553.00	151.00	m^3
Foundation	17,532.27	119.00	m^3
Foundation	92,670.57	629.00	m^3
Beds<150 thick	2,426.55	15.00	m^3
Beds>150 thick	123,592.28	764.00	m^3
Extra: Bed>150 thick	115,324.01	713.00	m^3
Walls.150 thick	31,545.15	195.00	m^3
Re-inforced Concrete: Grade C40/20-			
Slabs>150 thick	96,547.36	728.00	m^3
Beams, CS>0.10sqm	40,862.03	253.00	m^3
Columns,CS<0.10sq.m	175.95	1.00	m^3
Columns,CS>0.10sq.m	6,788.32	44.00	m^3
Walls>150 thick	20,441.34	139.00	m^3
Sundries in concrete work-			
constuction joints,etc	14,103.87		
constuction joints,etc	8,926.50		
Reinforcement-			
Bar; Straight or bent	465,142.45	444.19	tonnes
Fabric:A12; 2.22kg/m2; 100 laps	353.50	50.00	m^2
Concrete Work: Form Work			
Sides of Foundation, >500 high	32,029.89		
Edges of beds, 250-500 high	4,573.20		
recesses for aco drain, 1 side measured	5,063.97		
Walls	3,180.81		
Columns; rectangular	600.75		
Columns; Isolated-rectangular	17,617.18		
Corbels, attached to retaining walls	17,051.56		
Vertical Walls	40,821.14		
Opening in walls	801.22		
Soffits of slabs	110,893.50		
Openings	4,532.11		
Walls	73,262.16		
Sundries-			
Waterproffing	96,731.44		
Petrol Interceptor	3,469.37		
Additional Work, drainage	10,000.00		

INTERNAL WALLS			
Concrete Blocks: dense aggregate; I.S.20			
type A(5) 440x215x100; cement lime			
mortar (1:1:6):	107,208.75	1,375.00	m^2
Crushing Strength 10N/sq.mm	102,661.30	1,190.00	m^2
CS 15N/Sq.mm	234,120.45	2,577.00	m^2
CS 20N/Sq.mm	129,106.24	1,289.00	m^2
CS 30 N/Sq.mm			
	4,925.20		
Bonding			
Sundries-	8,906.00		
Joinery	10,000		
Additional Work for internal walls			
FLOORS			
ConcreteWork in Concrete Framed			
Structure:	5,515.00	50.00	m^3
In-Situ Concrete Grade C10N			
Re-inforced Concrete Grade C40/20-	216,766.44	1,474.00	m^3
Slabs	111,081.60	720.00	m^3
Beams			
Upstands-	703.80	4.00	m^3
X <0.10sq.m	1,453.59	9.00	m^3
X>0.10sq.m			
Surface Finishes-	55,216.16	12,752	m^2
surface of concrete slab,>300mm wide	859.18		
trowelling			
	9,521.60		
Joints			
Precast Prestressed Concrete Work			
Suspended floor units, 200 thick	2,860.50	50.00	m^2
Span not exceeding 5m	542.00		
raking cutting	693.80		
curved cutting	563.80	8,449.00	m^2
Span 5-7m	4,065.00		
cut for steel top flang	492,999.15		
Cut hole in floor unit			
Reinforcement	400,563.46	382.52	tonnes
Straight or Bent	396.50	50.00	m^2
Reinforcement mesh, A142, lapped 400			
Form Work	47,640.06		
Edges of suspended slabs and landing	134,044.95		
Soffits of slabs over 300mm wide	3,843.37		
Extra over: soffit height > 4m	176,315.40		
Beam: isolated X>010sq. M; soffits<4m	3,949.10		
Soffits height >4m	88,143.48		
Extra Foregoing formwork			

Sundries:	5,000.00		
Additional Work for susoended floors			
STAIRS			
Concrete Work			
Reinforced in-situ concrete Grade C40-	14,953.32	73.00	m^3
Steps			
Sundries in concrete work-	3,113.88		
Trowelling			
Reinforcement:	9,173.20	8.76	tonnes
Bars, straight, bent			
Formwork with type C finishes-	29,489.47		
Edge of suspended slab and landing	23,175.00		
Stairs	74,020.38		
Soffits of landing not exceeding 4m	6,437.70		
Soffits of stairs not exceeding 4m			
Precast Concrete Work	184,231.88		
Staircase			
ROOF			
Concrete work in concrete frame structure:			
Reinforcement in-situ concrete C40/20-	21,323.70	145.00	m^3
Slabs<150 thick	29,441.64	222.00	m^3
Slabs>150 thick	6,942.60	45.00	m^3
Beams,X>0.10sq. M	5,588.28	38.00	m^3
Walsl to rooflight, >150 thick			
Surface Finishes	12,890.41		
Powerfloating: surface of concrete,>300			
	1,679.52		
Joints			
Precast Prestressed Concrete Work	114,514.30		
Cuttings			
Reinforcement	77,145.02	73.67	tonnes
Straight or Bent	158.60	20.00	m^2
Reinforcement mesh A142, lapped 400			
FormWork	3,914.00		
Edges of suspended slabs and landing	37,095.56		
soffits of slabs	25,737.21		
walls			
Beams, isolated; X >0.10sq m; soffits	19,405.20		
height not greater than 4m	4,240.14		
Edges of openings in susoended slabs			
	2,000.00		
Sundries-			

Additional work in roofs			
FRAME			
Concrete Work			
Reinforced in-situ concrete Grade 40N	1,055.70	6.00	m^3
X<0.10 sq m	10,336.76	67.00	m^3
x> 0.10 sq m	145,295.28	988.00	m^3
walls>150 thick			
Reinforcement	139,441.16	133.16	tonnes
Straight or Bent			
Formwork			
Type B Finish	1,144.25		
kickers, rectangular columns	3,656.50		
isolated rec colums, X <0.10sq. M	28,170.50		
isolated rec colums, X >0.10sq. M			
Type C Finish	5,906.48		
Walls, kickers	569,823.66		
Vertical Wall, >4m	686.70		
Opening in wall, area<1 sqm	16,662.88		
Opening in wall, area>1 sqm			
	400.50		
Anchor Slots			
	5,000.00		
Additional Work in connection with frame			
TOTAL	5,536,402.60		

APPENDIX VIII

Bill of Quantities: Apartment Building 2

Description	Expenditure [€]	Quantity	Unit
PILING			
Augier driven ples to external basement wall	1,202,747.00		
Remove piles from site	42,317.36		
Breaking head of concrete pile	21,968.36		
BUILDERS WORK			
Excavation			
Removing excavated materials	104,214.60		
Disposal excavated material	104,214.60		
Disposal of heavy contaminated material	361,405.80		
Disposal of midly contaminated material	61,104.29		
Disposal: extra over, contaminated material	44,618.00		
Disposal, Extra over, mildly contaminated	23,757.50		
Disposal, inert contaminated material	14,813.67		
Filling			
Hardcore filling	79,577.76		
Additional works connected with piling	15,000.00		
SUBSTRUCTURE			
Excavation and Earthworks			
Excavation-Reduce Levels	57,634.60		
Removing from site	26,564.75		
Excavation, starting from reduced level	18,053.20		
Excavate for soft spots	91,055.20		
Disposal	2,906,714.92		
Filling	151,917.00		
Concrete Work			
Insitu concrete; Grade C10	20,004.33	1,819.00	m^3
In-situ concrete; Grade C30	31,788.00	300.00	m^3
In-situ concrete, grade C35/10	7,352.24	38.00	m^3
In-situ concrete, grade C35	611,247.10	5,521.00	m^3
Form Work			
Sides of foundation-	52,643.84		
Forming Service ducts	9,719.24		
Formwork with fair surface finish	62,198.86		
Soffits of slabs-			
slab thickness 300mm			
ramps			
Formwork with fair surface finish	323,083.78		
Sundries	7,558.02		

Sumps	29,531.39		
Surface Finish	10,738.88		
Reinforcement			
Bar, straight, bent	958,404.58	1,193.01	tonnes
Reinforcement			
inforcement fabric	19,256.41	3,859.00	m^2
Waterproofing			
rawmat type S1 waterproofing membrane	238,930.75		
Protection to tanking membrane	60,877.72		
Sundries			
Hydrophilic Waterbar	79,745.04		
Design joints	2,575.00		
Cont. design joints	6,070.68		
Insulation, Kingspan Kooltherm 50	73,166.64	3,859.00	m^2
Metalwork			
Structural	1,934.40		
Linemarking			
Roadlines	4,397.07		
Contamination Premium: Disposal	200,000.00		
Additional Work, substructure	25,000.00		
Sump pump	10,000.00		
EXTERNAL WALLS			
Concrete Work			
Insitu concrete, Grade C35, wall	6,336.50	58	m^3
Reinforcement			
Bar, straight, bent	7,688.05	9.57	tonnes
Formwork			
Formwork with fair finish	12,598.23		
cont. form work with fair finish	13,305.12		
Blockwork			
concrete blocks	6,701.28	184	m^2
Ancilliaries to blockwork	2,177.16		
cont. Ancilliaries to blockwork	1,529.40		
Insulation			
Wall insulation, Kingspan, TW50	4,594.20	494	m^2
firestopping to heads, jambs and cills	6,669.00		
Waterproofing			
Painting	2,964.00		

Additional work to external walls	10,000.00		
INTERNAL WALLS			
Brick and Block Work			
Concrete Blocks	28,881.06	793	m^2
Ancilliaries to Block Work	8,221.23		
Modification to groundfloor plan	20,000.00		
INTERNAL RC WALLS			
Concrete Work			
Insitu concrete Grade C35	43,263.00	396	m^3
Reinforcement			
Bar, straight, bent	52,490.89	65.34	tonnes
Formwork			
Formwork	120,304.87		
Sundries	5,000.00		
FLOORS			
Concrete Work			
Insiu concrete Grade C35	212,860.22	2,018.00	m^3
Insitu concrete, C30, screed	4,232.80	37.00	m^3
Reinforcement			
Bar, Straight and bent	320,175.15	398.55	tonnes
A142, horizontal	1,413.12	368.00	m^2
Formwork			
Formwork with fair finish	230,673.32		
cont. formwork	24,135.38		
Sundries			
Surface finish	20,108.45		
Insulation			
Kingspan Thermafloor TF70	3,124.94	442.00	m^2
STRUCRURAL STEEL WORK			
Fabricated steel members	51,548.23	24.07	tonnes
Sundries			
Balcony fixing	8,898.40		
Site Welding	2,418.00		
Protective Coating	12,222.26		
Additional work to floors	35,000.00		
STAIRS			

Concrete Work			
Insitu Concre, Grade C35	12,115.60	70.00	m^3
Sundries			
Sundries in concrete	881.28		
Reinforcement			
Straight or bent	8,435.18	10.5	tonnes
Formwork	49,613.42		
Additional work to stairs	25,000.00		
ROOFS			
Concrete Work			
Concrete Slabs, <150 thick	3,146.36	28.00	m^3
composite decking, <150 thick	22,249.26	198.00	m^3
in-situ concrete, Grade C35: Slabs			
>150 thick	9,886.08	96.00	m^3
Plinths:			
450x450x750 high, reinforced	1,332.72	8.00	m^3
200x450x750 high reinforced	166.59	1.00	m^3
Sundries in concrete work			
Surface finish on concrete			
Power floating	4,281.28		
trowlling tops of plinths	116.71		
Composite Construction			
Composite units, 60 thick:			
<5m span	23,625.36		
Composite units, 35 thick:			
<5m span	3,385.80		
reinforcement			
bars, straight or bent			
>12,<25 diameter	20,806.77	25.90	tonnes
>12 diameter	2,080.68	2.59	tonnes
Mesh reinforcement, A252 horizontal	3,746.12	1,574	m^2
Formwork			
Formwork with fair finish			
Insulation			
Kingspan Thermafloor TF70	11,128.18	1,574.00	m^2
Additional work on roofs	5,000.00		
FRAME			
Concrete work			
Columns, X area > 0.10m2	22,594.23	171.00	m^3

Reinforcement			
Bars, links or bent	45,333.04	56.43	tonnes
Formwork			
Formwork with fair finish			
Structural Steel			
Grade s275	43,019.84	26.88	tonnes
steel work cont	42,451.38	23.67	tonnes
Sundreis			
Shear studs	2,654.82		
Site welding	1,450.80		
Protective Coating	21,418.20		
Additional steel work	105,000.00		
EXTERNAL WALLS			
Supply and installation of glaazing	2,733,915.00		
Balustrades to Balcony	320,500.56		
Additonal work, fitting	60,000.00		
INTERNAL WALLS			
Internal doors, wood	94,908.76		
Internal doors, wood	185,816.18		
Ironmongery	19,199.24		
Ironmongery	17,468.56		
Ironmongery	961.47		
Additional Work, fit out	80,000.00		
STAIRS COMPLETION			
Hand rails and Balustrades	82,838.94		
Additional Work, stairs	20,000.00		
ROOF COMPLETION			
Smoke Vent	19,491.36		
Additional work for roof	13,000.00		
EXTERNAAL WALL FINISHES			
For the supply and installation of cladding	450,000.00		
Insitu Finishes:			
Walls	59,141.55		
Sundries:	5,300.62		
Allowance for Kingspan cladding	25,000.00		

INTERNAL WALL FINISHES			
Plaster work	22,650.21		
Drylining	206,420.16		
Woodwork	194,683.49		
Tiles, slabs and mosaic finishes	160,363.90		
Tiles, slabs and mosaic finishes	13,851.38		
Additional work with cladding	10,000.00		
FLOOR FINISHES			
Stone work			
Treads and Risers	24,099.96		
Sundries and Tile finishes	47,656.18		
Tiled finish			
Floors	85,736.57		
Additional Work	20,990.60		
CEILING FINISHES			
Plasterboard and suspended ceiling			
Making good, cuttings	72,258.09		
Sundries	70,199.81		
	31,576.40		
ROOF FINISHES			
Precast concrete paving slabs	13,043.34	466	m^2
Mastic asphalt roofing			
Rigid sheet covering and decking	97,359.85		
	30,033.06		
Fall Arrest System			
Additional work in connection with roof	4,630.95		
	10,000.00		
PAINTING AND DECORATING			
Plaster work	55,772.53		
Gloss paint to wood work	3,877.02		
DRAINAGE AND RAINWATER DISPOSAL			
uPVC pipes and fitting	21,285.22		
Drainage above ground	41,763.25		
Drainage above ground	3,535.03		
Additional work to rainwater disposal	2,000.00		
MECHANICAL INSTALLATIONS			
Waste, water, Gas, heating, HVAC, etc	1,032,300.00		
Sundries	13,083.66		
Sundries	42,838.68		
Sundries	47,446.18		
Flexible Sheet Finishes	23,816.88		

Additional work, floor ducts	10,000.00		
TRANSPORT'N SERV INSTALLATIONS			
Lift Services Instalaltion	261,450.00		
Bases and Additional work	8,245.12		
ELECTRICAL SERVICES INSTALLATIONS			
Distribution, General, Lighting, Comm, etc	1,440,598.00		
Trenches for cables	9,556.00		
Lighting Protection	5,699.68		
Holes through blocks, conduits, etc	8,341.62		
Holes through blocks, conduits, etc	10,771.76		
Holes through blocks, conduits, etc	7,515.60		
SANITARY FITTINGS			
WC, Urinal, Wash Basins.	91,953.24		
WC, Urinal, Wash Basins.	43,157.28		
Accessories, screwing to blocks	1,323.00		
Glazing	4,465.80		
AdditionalWork	50,000.00		
FITTING AND FURNITURE			
Supply and installation of fittings	49,500.00		
TOTAL	18,615,684.59		

APPENDIX IX

Bill of Quantities: Apartment 3

Description	Expenditure [€]	Quantity	Unit
GENERAL FACILITIES AND OBLIGATIONS	1,402,813		
SUBSTRUCTURE			
CONCRETE WORK :			
reinforcement insitu concrete Grade C40	31,298.40	280	m^3
slabs>150 thick	119,673.36	1,041	m^3
Reinforcement, Straight or bent	153,620.37	156	tonnes
FORMWORK	18,534.87		
Excavation and earth work	27,120.55		
Disposal	29,902.60		
Excavation and earth work	33,967.00		
Sundries	126,354.42		
EXTERNAL WALLS			
Blockwork;440 x 215 x 100; (1:1:6), 20N/mm^2			
100 thick	120,805.26	,	m^2
215 thick	13,776.84	252	m^2
forming cavities	22,039.43		
expansion joint; provisionally	4,664.00		
damp proof course	2,535.00		
preformed caity tray	3,214.00		
lintels	756.00		
INSULATION	32,934.13	5,000.00	m^2
additional work	5,000.00		
INTERNAL WALLS			
Partitions; fixing at base and head to precast concrete slab	556,621.06		
Partitions; fixing at base and head to precast concrete slab	468,236.70		
SOFTwood stud partition,2700 high	188,454.00	1923	m
3400high	1,115.19	47	m
FIRE INSULATION	12,312.00	684	m
ADDITIONAL WORK	500.00		
SOFTwood stud partition,2700 high	51,254.32	338	m
floors and galleries			
CONCRETE WORK IN CONCRETE			

FRAMED STRUCTURE			
Reinforced in-situ concrete Grade C40N;	490,899.02		
vibrated	26,137.90		
		4007	m^3
Slabs	34,397.52	194	m^3
beams			
	2,300.00		
Surface Finishes			
	318,807.72		
Designed joints			
	6,890.00	7996	m^2
PRECAST PRESTRESSED CONCRETE			
WORK	529,635.35		
cutting	41,076.18		
		527	tonnes
Reinforcement, Straight or bent	248,434.40	10614	m^2
mesh A142			
	91,811.10		
FORMWORK			
	130,590.94	10614	m^2
insulation, kingspan TF70, 50mm thick			
	2,000.00	94	tonnes
STRUCTURAL STEELWORK			
Sundries	2,500.00		
STAIRS			
WOODWORK	36,499.83		
PRECAST CONCRETE WORK	3,098.38		
FIXING AND FITTING			
		79	m^2
PRECAST PRESTRESSED CONCRETE	795.00		
WORK	3,498.00		
raking cutting	41,570.00		
Cut or form hole in floor unit (All Provisional)			
additional work in connection with stairs			
FRAME			
CONCRETE WORK	114,854.25		
In-Situ Concrete; Grade C35N/mm2	15,380.67	917	m^3
^^exceeding 150mm; Concrete fibre mesh			
reinforced	17,313.49	129	m^3
^^Beams; cross-sectional area exceeding			
0.10m2	110,033.61	139	m^3
Columns			
	418,499.77	110	tonnes
REINFORCEMENT			

FORMWORK			
	943.60		
BRICKWORK AND BLOCKWORK	2,122.65		
440 x 215 x 100; , 20 N/sq. mm; (1:1:6);		40	m^2
100 thick; provisionally		45	m^2
215 thick	2,358.50		
15 N/sq. mm; (1:1:6);	177,335.13	50	m^2
215 thick	49,335.58		
	49,352.96	74	tonnes
STRUCTURAL STEELWORK		19	tonnes
FABRICATED MEMBERS	530.00	15	tonnes
Fabricated members; beams			
	75,000.00		
FIXING SHEAR STUDS			
	378,028.00		
ADDITIONAL WORK			
FIXING WOOD WORK			
FLOORS, GALLERIES: COMPLETIONS	546,952.00		
STAIRS COMPLETIONS	73,854.00		
EXTERNAL WALL FINISHES	308,475.00		
INTERNAL WALL FINISHES	192,731.00		
FLOOR FINISHES	496,616.00		
CEILING FINISHES	447,080.00		
ROOF FINISHES	452,893.00		
PAINTING AND DECORATING	322,273.00		
DRAINAGE AND REFUSE DISPOSAL Installation	285,205.00		
MECHANICAL INSTALLATION Mechanical Services Installation	1,117,593.00		
ELECTRICAL INSTALLATION	1,135,120.00		
SANITARY FITTINGS	679,340.00		
FITTINGS & FURNITURE	516,977.00		
BUILDERSWORK IN CONNECTION WITH SERVICES	121,720.00		
EXTERNAL WALLS: COMPLETIONS			

glazing and window installation	2,065,173.00		
TRANSPORT			
Lift Services Installation	120,000.00		
PREPARED SITE			
EXCAVATION AND EARTHWORKS	30,202.00		
SITE ENCLOSURES			
Firewall	5,000.00		
ROADS, PATHS AND PAVING			
EXCAVATION AND EARTHWORK			
150 thick in-situ concrete paving	200.00	20	m^2
CABLES AND PIPES			
EXCAVATING	33,921.94		
Plain in-situ concrete Grade C12/20N	13,368.76	122	m^3
PRE-FORMED PAVING AND EDGING UNITS			
SAND STONE PAVING	113,764.91	2,631	m^2
ADDITIONAL WORK	5,000.00		
SITE SERVICES - PIPED & DUCTED			
Drainage, excavation,	132,956.06		
GAS INSTALLATION	13,688.94		
Plain in-situ concrete; Grade C20 as specified	88.00	1	m^3
Reinforced in-situ concrete Grade C35/20; vibrated	545.00	5	m^3
SITE SERVICES – ELECTRICAL	26,781.00		
SITE FITTINGS			
EXCAVATION AND EARTHWORK	628.11		
IN-SITU CONCRETE,Plain in-situ Grade C10	2,256.66		
FORMWORK	2,384.64		
FITTINGS; EQUIPMENT & FURNITURE	232,716.80		
LANDSCAPING	6893		
TOTAL	15,141,353.87		

APPENDIX X

Bill of Quantities: Apartment 4

Description	Expenditure [€]	Quantity	Unit
SUBSTRUCTURES			
EXCAVATION AND EARTHWORKS	51,133.92		
Disposal	53,008.95		
blinding filling; 50 thick sand	1,012.50		
In-Situ Concrete; Grade 15N20	36,572.34		
In-Situ Concrete; Grade C35N20; reinforced	38,392.85	399	m^3
		387	m^3
concrete screed; grade 20; mix (1:3-4.5)			
including steel fibre reinforcment;			
Sundries	5,890.22		
Surface finishes	3,222.20		
FORMWORK	11,534.02		
ROOFING CLADDING AND	2,539.00		
WATERPROOFING			
REINFORCEMENT	22,478.28		
Fabric; reference A393, lapped 400,	2,455.88		
Fabric; reference A252,	4,050.75		
		22	tonnes
BRICKWORK AND BLOCKWORK		343	m^2
concrete blocks; 440 x 215 x 100;		825	m^2
10 N/sq mm; (1:1:6);			
100 thick	4,203.36		
215 thick	16,082.85		
forming cavities	1,134.00		
SUNDRIES	8,534.50	126	m^2
		265	m^2
INSULATION			
horizontal; 60mm thick			
vertical; 25 thick x 225 high	3,298.96		
60 thick protection to damp proof membrane	285.12		
	402.78		
cut and sealing			
additional work	4,491.86	344	m^2
	15,000.00	132	m
EXTERNAL WALLS			
CONCRETE WORK			
cast stone cills	19,731.49		
Lintels; Precast Concrete Lintels	17,809.67		
100 x 65mm			
215 x 65mm	3,061.14		
	5,653.26		
Stainless steel steelite lintels			
	15,681.00		
ACCESSORIES			
installation			
	5,586.00	313	m
BRICKWORK AND BLOCKWORK		342	m
Blockwork; concrete blocks; dense aggregate;			
100 x 215 x 440;			

100mm thick cavity walls			
215mm thick cavity walls	31,950.56		
215mm thick solid blockwork walls	80,891.67		
	15,792.30		
Brickwork, 1:2 mix			
100mm thick to walls			
215mm thick	69,190.81		
	36,055.95		
ANCILLARIES IN BLOCKWORK		1006	m^2
forming cavities		1383	m^2
	23,039.00	270	m^2
insulation			
Insulation board; Kingsn,Thermawall TW50			
100mm thick;			
20 thick x 70 dp;	13,802.34	377	m^2
20 thick x 150 wide;	1,561.14	115	m^2
	1,149.04		
additional work			
	5,000.00		
INTERNAL WALLS			
Blockwork; concrete blocks; dense aggregate;			
size 100 x 215 x 440;			
215 thick	21,524.32	1383	m^2
		294	m
ANCILLARIES TO BLOCKWORK	1,047.00	424	m
Partitions	50,427.22		
FLOORS			
In-situ concrete floors; concrete Grade35N			
slabs; exceeding 150mm thick; reinforced	28,360.92		
concrete screed; grade 20; mix (1:3-4.5)			
including steel fibre reinforcement;		368	m^2
75 thick; to minimum falls of 1:60	36,502.80		
Surface finishes, Power floating	7,108.52		
Reinforcement	67,823.10		
FORMWORK	24,194.12		
PRECAST CONCRETE			
200mm thick; span ,7.00 m	34,798.75	266	m^3
Sundries	4,847.92		
INSULATION			
Kingspan Thermafloor TF70, over 300 wide	15,535.80	3202	m^2
Structural and first fixings;	1,657.00		
Fabricated Members , steel work	68,838.90	66.38	tonnes
Fixing	23,104.00		
STAIRS; RAMPS			

CONCRETE WORK		875	m^2
1.20m wide	204.90		
Surface finishes	33.00		
PRECAST CONCRETE, flood flooring	9,639.00		
		1620	m^2
ROOFS			
IN-SITU CONCRETE ROOFS			
In-situ concrete floors; concrete Grade35N			
slabs; exceeding 150mm thick; reinforced	1,919.16		
		27.87	tonnes
concrete screed; grade 20; mix (1:3-4.5);			
75 thick; to minimum falls of 1:60	2,499.78		
Surface finishes	591.96		
Reinforcement	1,614.35		
150 laps; ref A252	250.41		
		10	m^2
FORMWORK	2,426.40		
Structural and first fixings;	21,741.07		
ROOF INSULATION			
Kingspan Thermafloor TF70			
60 thick	1,342.60		
Kingspan Kooltherm K7 ,1200mm thick,			
over 300 wide	14,204.40	18	m^3
STRUCTURAL STEELWORK			
254 x 146 x 43 UB	2,247.70		
		122	m^2
Additional work	10,000.00		
FRAMES			
Reinforced in-situ concrete Grade C35 vibrated			
exceeding 150mm thick; reinforced	4,799.25	1.58	tonnes
cross-sectional area over 0.10 sq m	1,325.61	51	m^2
cross-sectional area not exceeding 0.10 sq m	4,343.85		
cross-sectional area over 0.10 sq m	4,716.18		
nominal length 450mm; X< 0.10 sq. m	124.11		
Surface Finishes; trowelling tops of beams	414.16		
Bar; straight or bent	28,996.98		
FORMWORK	64,601.63		
		140	m^2
PRECAST CONCRETE			
215 x 215mm; to external walls	736.82		
		760	m^2
Structural and first fixings;	4,410.00		
additional work	5,000.00	0.91	tonnes
EXTERNAL WALLS COMPLETIONS	266,233.00		
INTERNAL WALL COMPLETIONS	60,686.00		

STAIRS COMPLETIONS	48,780.00	45 11 35 38 1	m^3 m^3 m^3 m^3 m^3
EXTERNAL WALL FINISHES	109,086.00		
INTERNAL WALL FINISHES	148,431.00		
FLOOR FINISHES	64,058.00		
CEILING FINISHES	41,488.00	28.38	tonnes
ROOF FINISHES	147,046.00		
PAINTING AND DECORATING	56,253.00		
RAINWATER INSTALLATION	68,079.00	19	m
MECHANICAL INSTALLATION	400,575.00		
BUILDERSWORK FOR MECHANICAL INSTALLATION	9,288.00		
	198,557.00		
ELECTRICAL INSTALLATION			
	34,969.00		
BUILDERSWORK FOR ELECTRICAL INSTALLATION			
	18,998.00		
SANITARY FITTINGS	76,448.00		
FITTINGS & FURNITURE			
TOTAL	2,954,608.40		

APPENDIX XI

Bill of Quantities: Apartment 5

Description	Expenditure [€]	Quantity	Unit
SUBSTRUCTURES			
EXCAVATION AND EARTHWORKS	2,419.58		
Disposal			
filling to foundations; average thickness	6,020.96		
exceeding 250mm	6,436.20		
Surface treatments	241.65		
In-Situ Concrete; Grade 15N20	1,9431.92	2121	m^3
In-Situ Concrete; Grade C35N20;			
reinforced; vibrated	9,586.08	99	m^3
concrete screed; 73mm thick G20;(1:3-4.5)	4,081.2	358	m^2
including steel fibre reinforcment;			
cavity walls	746.55	7	m^3
Surface finishes	1,689.47		
REINFORCEMENT			
Fabric; reference A393, lapped 400,	895	125	m^2
Fabric; reference A252, lapped 400,	1,281.64	179	m^2
BRICKWORK AND BLOCKWORK			
size 440 x 215 x 100; 10 N/sq mm; (1:1:6);			
100 thick	1,567.92	47	m^2
215 thick	4,369.68	72	m^2
ANCILLARIES TO BRICKWORK AND BLOCKWORK			
Forming Cavities	270.25		
SUNDRIES	1,850.90		
Floor insulation; laid to underside of floor slab			
horizontal; 60 thick	1,716.61	179	m^2
horizontal; 60 thick	1,716.61	179	m^2
vertical; 25 thick x 225 high	347.76	161	m
filling	3,277.96		
additional work	5,000.00		
EXTERNAL WALLS			
Reinforced in-situ concrete Grade C35 vibrated			
cross-sectional area not exceeding 0.10 sq m	1,489.32	12	m^3
nominal length 450mm; x<0.10 sq. m	124.11	1	m^3

Bar; straight or bent			
12 - 25 diameter	549.46	0.56	tonnes
not exceeding 12 diameter	61.3	0.06	tonnes
FORMWORK	5,677.2		
PRECAST CONCRETE	22,204.17		
preforemed cavity	1,159		
BRICKWORK AND BLOCKWORK	56,666.39		
concrete ,100 x 215 x 440;		1461	m^2
	68,456.69		
100mm thick to walls		373	m^2
ANCILLARIES IN BLOCKWORK			
forming cavities	13,730.27		
INSULATION			
Insulation board; Kingsn,Thermawall TW50	6,936.1		
100mm thick;	323.91	695	m^2
20 thick x 70 dp;	262.87	61	m
20 thick x 150 wide;		97	m
STRUCTURAL STEELWORK			
support	2,898		
Fabricated members	5,900	2.36	tonnes
coating	826		
additional work	5,000		
INTERNAL WALLS			
BRICKWORK AND BLOCKWORK			
concrete blocks; 100 x 215 x 440;			
100mm thick	3,308.76	101	m^2
215mm thick	21,524.32	368	m^2
ANCILLARIES TO BLOCKWORK	676.2		
DAMP PROOF COURSE	182.36		
Partitions	36,714.87		
FLOORS			
In-situ concrete floors; concrete Grade20			
slabs; exceeding 150mm thick; reinforced			
concrete screed; grade 20; mix (1:3-4.5)	4,970.4	436	m^2
including steel fibre reinforcment;			
75 thick; to minimum falls of 1:60			
Surface finishes, Power floating	719.4		
PRECAST CONCRETE			
200mm thick; span >5.00 <7.00 m;	8,669.86	218	m^2
Sundries	325		
Fixings	9302.62		
INSULATION			
Kingspan Thermafloor TF70, over 300 wide	2,090.62	218	m^2

STRUCTURAL STEELWORK Welding	3,507.4 33.25	1.42	tonnes
STAIRS; RAMPS			
CONCRETE WORK			
fixing woodwork			
ROOFS Structural and first fixings; ROOF INSULATION over 300 wide	 14,896.45 5,645.32	 214	 m^2
STRUCTURAL STEELWORK 254 x 146 x 37kg/m Universal Beam;	 6,323.2	 2.56	 tonnes
additional work	5,000		
EXTERNAL WALLS COMPLETIONS	60,966		
INTERNAL WALL COMPLETIONS	55,265		
STAIRS COMPLETIONS	42,900		
EXTERNAL WALL FINISHES	41,024		
INTERNAL WALL FINISHES	87,959		
FLOOR FINISHES	28,735		
CEILING FINISHES	20,106		
ROOF FINISHES	66,323		
PAINTING AND DECORATING	32,223		
RAINWATER INSTALLATION	62,616		
MECHANICAL INSTALLATION	178,101		
BUILDERSWORK FOR MECHANICAL INSTALLATION	3,546		
ELECTRICAL INSTALLATION	19,067		
BUILDERSWORK FOR ELECTRICAL INSTALLATION	4,438		
SANITARY FITTINGS	15,362		
FITTINGS & FURNITURE	51,407		
TOTAL	1,176,249.78		

APPENDIX XII

Bill of Quantities: Apartment 6

Description	Expenditure [€]	Quantity	Unit
SUBSTRUCTURES			
EXCAVATION AND EARTHWORKS	381.22		
Disposal	851.62		
filling to foundations; average thickness exceeding 250mm	1,829.90		
Surface treatments	72.90		
CONCRETE WORK			
In-Situ Concrete; Grade 15N20	3,574.74	39	m^3
In-Situ Concrete; Grade C35N20; reinforced; vibrated	2,721.72	28	m^3
concrete screed; 75mm thick G20;(1:3-4.5) including steel fibre reinforcement;	1,231.2	108	m^2
cavity walls	639.9	6	m^3
Surface finishes	320.22		
FORMWORK	376.80		
Fabric; reference A393, lapped 400,	243.44	34	m^2
Fabric; reference A252, lapped 400,	265.14	54	m^2
BRICKWORK AND BLOCKWORK			
size 440 x 215 x 100; 10 N/sq mm; (1:1:6);			
100 thick	1,234.32	37	m^2
215 thick	2,245.53	37	m^2
ANCILLARIES TO BRICKWORK AND BLOCKWORK			
Forming Cavities	212.75		
SUNDRIES	518.40		
Floor insulation; laid to underside of floor slab			
horizontal; 60 thick	517.86	54	m^2
horizontal; 60 thick	517.86	54	m^2
vertical; 25 thick x 225 high	120.96	56	m
filling	532.00		
additional work	2,000.00		

EXTERNAL WALLS			
Reinforced in-situ concrete Grade C35 vibrated cross-sectional area not exceeding 0.10 sq m	744.66	6	m^3
Bar; straight or bent	919.57	0.9	tonnes
<12diameter	91.96	0.09	tonnes
Bars; links or the like			
	2,928.24		
FORMWORK			
	6,078.16		
PRECAST CONCRETE			
	494.00		
preforemed cavity			
BRICKWORK AND BLOCKWORK	26,097.73	647	m^2
concrete ,100 x 215 x 440;			
	15,416.52	84	m^2
100mm thick to walls			
ANCILLARIES IN BLOCKWORK	7,081.84		
forming cavities			
INSULATION			
Insulation board; Kingsn,Thermawall TW50	3,133.72	314	m^2
100mm thick;	127.44	24	m
20 thick x 70 dp;	75.88	28	m
20 thick x 150 wide;			
	370.50	0.15	tonnes
STRUCTURAL STEELWORK			
	2,000.00		
additional work			
INTERNAL WALLS			
BRICKWORK AND BLOCKWORK			
concrete blocks; 100 x 215 x 440;	1,169.80	20	m^2
215mm thick	6,025.23		
Partitions	42.68		
DAMP PROOF COURSE			
FLOORS			
In-situ concrete floors; concrete Grade20 slabs; exceeding 150mm thick; reinforced			
concrete screed; grade 20; mix (1:3-4.5) including steel fibre reinforcment; 75 thick; to minimum falls of 1:60	2,212.92	108	m^2
Surface finishes, Power floating	265.14	54	m^2
Fabric reinforcement, 150 laps; ref A252			

PRECAST CONCRETE 200mm thick; span >5.00 <7.00 m; Sundries Fixings	2,147.58	54	m^2
INSULATION Kingspan Thermafloor TF70, over 300 wide	517.86	54	m^2
STRUCTURAL STEELWORK Welding	2,286.65	1	tonnes
STAIRS; RAMPS Concrete Work & wood work fixing	4,164.00		
ROOFS	7,752.45		
Structural and first fixings; ROOF INSULATION over 300 wide	1,782.40	64	m^2
EXTERNAL WALLS COMPLETIONS	18,643.00		
INTERNAL WALL COMPLETIONS	11,277.00		
STAIRS COMPLETIONS	3,949.00		
EXTERNAL WALL FINISHES	22,255.00		
INTERNAL WALL FINISHES	18,037.00		
FLOOR FINISHES	4,332.00		
CEILING FINISHES	4,186.00		
ROOF FINISHES	18,836.00		
PAINTING AND DECORATING	6,734.00		
RAINWATER INSTALLATION	19,848.00		
MECHANICAL INSTALLATION	40,995.00		
BUILDERSWORK FOR MECHANICAL INSTALLATION	6,340.00		
ELECTRICAL INSTALLATION	6,403.00		
BUILDERSWORK FOR ELECTRICAL INSTALLATION	1,098.00		
SANITARY FITTINGS	3,084.00		
FITTINGS & FURNITURE	9,736.00		
TOTAL	317,845.95		

APPENDIX XIII

Bill of Quantities: Apartment Building 7

Description	Expenditure [€]	Quantity	Unit
SUBSTRUCTURE:			
EXCAVATION AND EARTHWORKS	637.96		
Disposal			
filling to foundations; average thickness exceeding 250mm			
Surface treatments			
CONCRETE WORK			
In-Situ Concrete; Grade 15N20	1,833.2	20	m^3
In-Situ Concrete; Grade C35N20;	13,455.36	146	m^3
concrete screed; 75mm thick G20;(1:3-4.5)	7,488.24	656	m^3
cavity walls	1,066.5	10	m^3
Surface finishes	1,945.04		
FORMWORK	2,612.48		
reinforcement, High Yield Bar; straight or bent	22,478.28	22	tonnes
Fabric; reference A252, lapped 400	1,610.48	328	m^2
BRICKWORK AND BLOCKWORK			
size 440 x 215 x 100; 10 N/sq mm; (1:1:6)			
100 thick	5,703.36	156	m^2
215 thick	9,467.64	156	m^2
ANCILLARIES TO BRICKWORK AND BLOCKWORK			
Forming Cavities	897		
SUNDRIES	3,440		
Floor insulation; laid to underside of floor slab			
horizontal; 60 thick	3,145.52	328	m^2
horizontal; 60 thick	3,145.52	328	m^2
vertical; 25 thick x 225 high	673.92	312	m
Filling	3,439		
Additional Work	5,156		
EXTERNAL WALL			
Copings to parapet, 560 x 150	6,730.15	67	m
Window cill	6,562.4		
Lintels; Precast Concrete Lintels, 100 x 65mm	3,063.86	307	m
Stainless steel steelite lintels	1,2576.84		
Accessories	2,337		
BRICKWORK AND BLOCKWORK			
concrete ,100 x 215 x 440;			
215mm	1,169.8	20	m^2
100mm thick to walls	6,3154.26		

Brickwork;mix:1:2, 100mm thick to walls	6,1115.49	1781 333	m^2 m^2
INSULATION			
Insulation board; Kingspan,Thermawall TW50			
100mm thick;	9091.78	911	m^2
20 thick x 70 dp;	653.13	123	m
20 thick x 150 wide;	411.92	152	m
STRUCTURAL STEELWORK			
externally; 50 x 90 x 10kg/m stainless steel	399		
100 x 100 x 12 rolled steel angle;	2,865.2	0.12	tonnes
fixing	1,1030.32	1.16	tonnes
additional work	5,000		
INTERNAL WALL			
Partitioning and making good	11,030.32		
FLOORS			
Carcassing in floors or flat roofs			
225 x 50 bridging	3,247.2	264	m
225 x 44 joists; trimmers etc.	9,803.1	797	m
244 x 44 double joists;	1,869.6	152	m
Fixing	2,855.9		
STARIS and RAMP	20,440		
ROOFS			
Carcassing in floors or flat roofs			
225 x 50 bridging	2,804.4	228	m
225 x 44 joists; trimmers etc.	1,4514	1180	m
extra over on above; chamfering ends of rafters			
100 x 75 wallplates	4,033.76	272	m
Accessories	2,096		
ROOF INSULATION			
over 300 wide	1,0972.9	394	m^2
EXTERNAL WALLS COMPLETIONS	7,3656		
INTERNAL WALL COMPLETIONS	65,752		
EXTERNAL WALL FINISHES	72,046		
INTERNAL WALL FINISHES	84,807		
FLOOR FINISHES	19,675		
CEILING FINISHES	19,022		
ROOF FINISHES	89,520		

PAINTING AND DECORATING	33,216		
RAINWATER INSTALLATION	39,672		
MECHANICAL INSTALLATION	209,535		
BUILDERSWORK FOR MECHANICAL INSTALLATION	17,682		
ELECTRICAL INSTALLATION	37,277		
BUILDERSWORK FOR ELECTRICAL INSTALLATION	2868		
SANITARY FITTINGS	13,005		
FITTINGS & FURNITURE	21,061		
TOTAL	1,228,208.50		

APPENDIX XIV: List of Publications

Journal Publication

- Acquaye, A, A and Duffy, A, P (2010) Input-Output Analysis of Irish Construction Sector Green House Gas Emissions; Building and Environment, vol. 45; issue 3; pp784-791

Journal Submissions: Under Review

- Acquaye, A, A; Duffy, A, P and Basu, B (2010) A Stochastic Hybrid Embodied CO_2-eq Analysis of Apartment Buildings in Ireland; Energy and Buildings; Under Review
- Acquaye, A, A; Duffy, A, P and Basu, B (2010) An Investigation of possible Embodied CO_2-eq Policies for the Built Environment; Energy Policy; Under Review

Conference Proceedings

- Acquaye, A, A; Duffy, A, P and Basu, B (2009) Assessing the energy and CO_2-eq emissions embodied in buildings towards a sustainable building design and construction; Second International Conference on Whole Life Urban Sustainability and its Assessment; 22-24 April 09, Loughborough, UK; ISBN: 139780947974 80 0

- Acquaye, A, A; Duffy, A, P and Basu, B (2009) Embodied Energy and CO_2-eq Analysis-An Assessment Tool for Sustainable Construction Process; Engineering Sustainability Conf: Innovations that Spans Boundaries, 19-21 April9; PA-USA

- Acquaye, A, A; Duffy, A, P and Basu, B (2007) ''Comparative Embodied Energy Analysis of a Steel and Concrete Structural System in Ireland'' International

Conference on Environmental Management, Engineering, Planning and Economics; Greece; 24-28 June 2007; Vol 1; pp 347-353; ISBN: 978-960-89090-8-3

Working Paper

- Acquaye, A, A and Duffy, A, P (2009) ‘’ Development of a Construction Sub-Sector Embodied Energy Hybrid Analysis; W/P1; http://arrow.dit.ie/dubenwp/1